UTILIZATION OF COAL IN METAL INDUSTRIES

(CASE OF AKAKI METAL PRODUCTS FACTORY)

BY

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Abstract

The ever increasing prices, poor energy source mix and limited supplies of energy resource is becoming a bottle neck for sustainable development strategies of the country and to achieve the millennium development goals. To alleviate this development obstacle, the country has to find another alternative locally available resource that can substitute the imported energy source (petroleum products). One of the potential resources the country owns is coal, greater than 300 million tons of proved lignite coal reserves in its different geological parts: Yayu, Moye and Delbi as the top three major reserve areas with 229, 40-50 and 20 million tons respectively and there are more than 23 occurrence localities identified yet.

This research raises and discuses the question of how coal resource in the country can be used in metal industries to substitute imported heavy fuel oils based on the current technology & demands to secure (facilitate) sustainable development of the country. This thesis therefore, is dedicated to demonstrate how coal can be used in metal industries and to propose a better system for both economic and environmental performances advantages.

The energy demand and consumption of the selected factories (1) Ethiopian Iron and Steel Factory, (2) Akaki Metal Products Factory and (3) Zuqalla Steel Rolling Mill Enterprise is meet from heavy fuel oil and electric power. Except, Akaki Spare Parts and Hand Tools Share Company which uses electric power as a major source of energy, heavy fuel oil accounts the major share.

For the Case Factory, the existing energy conversion system (oil fire furnace) is more flexible to use for the combustion of coal. By modifying to fluidize bed combustion, it is possible to utilize coal with better efficiency and easy control of emissions (sulfur and nitrogen oxides).

Therefore, the indigenous coal can play significant role to reduce the hard currency expenditure for the imported petroleum products and improve the energy source mix of the country, more over, coal in this application area will help the country to maintain the economic development strategies and make Ethiopia self-reliant in the energy supply.

Outline

This thesis has four parts in which six chapters are distributed with in them. The first part which covers the introductory section contains chapter one with the background, description of the study, and research question.

Part two contains literature reviewed in the process of the research. Chapter two in this part, looks at general overview of coal, particularly formation and types of coal, world coal reserves, use of coal, coal production & consumption and brief of energy resource and coal in Ethiopia.

The third part is chapter five which illustrates the discussions and analysis of energy demand and consumption pattern of selected factories, detailed demonstration of coal application is presented for Akaki Metal Products Factory. Finally, Conclusion and recommendations are the terminate part of the thesis.

Acronyms

ADO	Automotive Diesel Oil
AMPF	Akaki Metal Products Factory
BTU	British Thermal Units
CFCs	Chlorofluorocarbons
COFCOP	Coal- Phosphate Fertilizer Complex Project
DAP	Diammonium Phosphate
EIA	Energy Information Administration
EISF	Ethiopian Iron and Steel Factory
EPE	Ethiopian Petroleum Enterprise
FBC	Fluidized Bed Combustion
HFO	Heavy Fuel Oil
IEO	International Energy Outlook
IEO2006	International Energy Outlook 2006
JET A-1	Jet Fuel
LFO	Light Fuel Oil
LPG	Liquid Petroleum Gas
MGR	Motor Regular Gasoline
MT	Metric Ton
Non-OECD	countries outside the Organization for Economic Cooperation and Development
OECD	Organization for Economic Co-operation and Development
ROM	Run of- Mine
SD	Sustainable Development
UNDSD	United Nations Division for Sustainable Development
WCI	World Coal Institute
WEC	World Energy Council
ZuSRoM	Zuqalla Steel Rolling Mill Enterprise

Part One: Introduction

1.1 Background of the Study

The events of recent years have served to remind us to think of about the finite limited world's resources. As industrial economies mature, the heart of the environmental challenge comes from maintaining the continual flow of goods and services to satisfy society's needs for housing, food, energy, transport, and recreation while not destroying the natural resources that underlie the economy. The way society meets its needs determines the types and amounts of materials ranging from fuels and timber to fertilizers and metals that flow from the environment, through the economy, and back into the natural environment. Environmental consequences, good and bad, depend on the way a material is extracted, the nature of its release, how much is released, how it is released, and where it flows throughout its life cycle. A coherent approach to accounting for the flow of materials integrates two major concerns: the capacity of ecosystems to provide natural resources for extraction and use and the capacity of the earth and human society to handle pollution, greenhouse gases, toxic contamination, and other wastes [11].

Time is not on our side; resources, which until recently had been assumed to be freely available, suddenly resources of all types are becoming scarce, pollutants of many different types are increasing, and environmental problems are no longer local or even national in extent, but have reached international dimensions [18].

To ensure that our environmental and the resource base remain capable of supporting the people that inhabit the planet has placed unprecedented demands for new methods of governance and legislation up on governments and their advisors. Finding an equitable way of sharing out the remaining resources and at the same time ensuring an environment that will provide the best possible quality of life represents one of the greatest challenges ever faced this generation.

Coming to Ethiopia's energy resource condition, the country's energy demand is increasing from time to time due to high population growth industrial development improved living standards and other factors. More over most of the major economic sectors are dependent on imported petroleum products, while the prices of these products are increasing at alarming rates.

To alleviate these interrelated problems the country has to search alternative options that utilize locally available resources. For example recent exploration studies show that there are more than 300 million tons of coal reserves in different parts of the country, yet not put in to economic uses. Coal is one of the most important non-renewable natural local energy carrier mineral resources; it can contribute significantly for the economic growth and to make Ethiopia self-reliant as it can be used for different economic functions such as:-

- domestic fuel(source of energy for house hold);
- reducing agent in the production of sponge iron by direct reduction methods;
- fuel for thermal plants
    - ceramic plant processing;
    - cement manufacture;
    - steel mills
- fuel in the production of lime and bricks;
- for the production of chemical fertilizers;
- power generation(electric power);
- oil and gas generation etc

Now, plans for economic development have seriously affected by the uncertainty of energy supplies. Limited energy supplies and their increased prices have resulted in the escalation in prices of other commodities creating a difficult situation for millions of people to solve the challenges of the economic development. It is difficult to achieve the intended societal-based economic development depending only on the imported resources. The problem is therefore, how coal can be used to substitute the imported petroleum products.

1.2 Objectives

The general objective of this thesis is to find possibilities of coal utilization in metal industries as a substitution for heavy fuel oils.

The specific objectives are:

- survey the current energy consumption patters of selected metal industries;
- identify areas for coal application in the selected industries;
- demonstrate how coal can be used in the selected area for application;
- conduct material and energy balance for the selected application area;
- propose better method for utilization;

1.3 Methodology

The methods employed to achieve the objectives are:

1. review of literatures and previous relevant studies;
2. factories visit, energy consumption pattern and conversion system study;
3. study of the current system for coal utilization and required modifications;
4. theoretical quantification of emissions from the application;
5. material and energy balance

Part Two: Literature Review

2. Coal: General Overview

2.1. Coal Definition

Coal is a fossil fuel created from the remains of plants that lived and died about 100 to 400 million years ago when parts of the earth were covered with huge swampy forests. Coal is classified as a non-renewable energy source because it takes millions of years to form [32].

The energy in coal comes from the energy stored by plants that lived hundreds of millions of years ago. All living plants store energy from the sun through a process known as photosynthesis. After the plants die, this energy is released as the plants decay [8].

2.2. Coal Formation

Coal is a combustible, sedimentary, organic rock; it is a complex mixture of organic chemical substances containing carbon, hydrogen and oxygen in chemical combination, together with smaller amounts of nitrogen and sulfur. It is formed from vegetation, which has been consolidated between other rock strata and altered by the combined effects of bacterial action, pressure and heat over millions of years to form coal seams. The build-up of silt and other sediments, together with movements in the earth's crust (known as tectonic movements) buried these swamps and peat bogs, often to great depths. With burial, the plant material was subjected to high temperatures and pressures. This caused physical and chemical changes in the vegetation, transforming it into peat and then into coal [20].

Seams of coal ranging in thickness from a fraction of an inch to hundreds of meters may represent hundreds or even thousands of years of plant growth. One important coal seam, the seven foot thick Pittsburgh seam, may represent 2,000 years of rapid plant growth. One acre of this seam contains about 14,000 tons of coal [21].

Several stages are involved in the formation of coal. These are:-

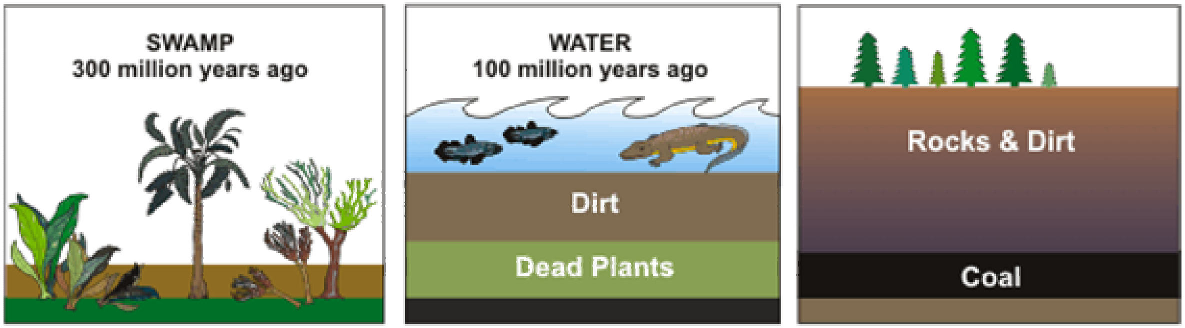
- Plant material, wood
- Peat
- Brown coal (lignite)
- Black coal (sub-bituminous, bituminous and anthracite)

Each successive stage has lower water content and higher energy content. This means that when the same quantity of each material is burnt, a greater amount of heat is released for each successive stage [32].

Coalification is the name given to the development of the series of substances known as peat, lignite or brown coal, sub-bituminous coal, bituminous coal, and anthracite. The degree of coalification, also called the rank of the coal, increases progressively from lignite low rank coal, to high rank coal, anthracite. The carbon content increases, while the oxygen and hydrogen contents decrease throughout the series, hardness increases, while the reactivity decreases [32].

Vegetation continued to grow for many generations and centuries, forming vast, thick peat beds which were later to turn into coal (Figure 1). After a time the areas of swamp gradually became submerged by shallow seas, where they were covered by sediment. These sediments would later become sedimentary rock. This cycle of swamp followed by submersion was often repeated a number of times, so that a sequence of horizontal bands of peat and inorganic, sedimentary rock was built up. This formed the first stage, called the biochemical stage subsequently, the bands of peat were altered by the action of pressure and temperature during the second, or geochemical stage, to form the various kinds of coal found today [28].

Figure 1: How Coal Was Formed [32]



Before the dinosaurs, many giant plants died in swamps.

Over millions of years, the plants were buried under water and dirt.

Heat and pressure turned the dead plants into coal.

2.3. <u>Types of Coal</u>

The term "coal" is used to describe a variety of fossilized plant materials, but no two coals are exactly alike. Heating value, moisture, ash, volatiles, melting temperature, sulfur and other impurities, mechanical strength, and many other chemical and physical properties must be considered when matching specific coals to a particular application [32].

The quality of each coal deposit is determined by temperature and pressure and by the length of time in formation, which is referred to as its ‘organic maturity’. Initially the peat is converted into lignite or ‘brown coal’ these are coal-types with low organic maturity. Over many millions of years, the continuing effects of temperature and pressure produces further change in the lignite, progressively increasing its organic maturity and transforming it into the range known as ‘sub-bituminous’ coals. Further chemical and physical changes occur until these coals became harder and blacker, forming the ‘bituminous’ or ‘hard coals’. Under the right conditions, the progressive increase in the organic maturity can continue, finally forming anthracite [23].

Coal is classified into four general categories or "ranks" (Figure 2); they range from lignite through sub-bituminous and bituminous to anthracite depending on the amounts and types of carbon it contains and on the amount of heat energy it can produce; reflecting the progressive response of individual deposits of coal to increasing heat and pressure. The carbon content of coal supplies most of its heating value, but other factors also influence the amount of energy it contains per unit of weight, for the most part, the higher ranks of coal contain more heat-producing energy [32].

There are many ways of classifying coal according to its chemical and physical properties; the most accepted system is the one used by the American Society for Testing and Materials (ASTM), which classifies coals by grade or rank according to the degree of metamorphism (change in form and structure under the influences of heat, pressure and water) [22].

2.3.1. <u>Lignite:</u>

Lignite (derived from the Latin Lignum, which means, ‘wood’, remnants of wood fiber are often visible init. It is the lowest rank of coal with the lowest energy content and relatively a geologically young coal deposits that were not subjected to extreme heat or pressure. It is crumbly and has high moisture content, which has the lowest carbon content, 25-35 percent, and a heat value ranging between 4,000 and 8,300 [2]BTUs-per-pound. Sometimes called brown coal, it is

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[2] The amount of energy in coal is expressed in British thermal units per pound, a BTU is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

mainly used for electric power generation. In comparison to other coals, lignite is quite soft and its colour can range from dark black to various shades of brown. Because of the high moisture content and low heating value [26].

2.3.2. Sub-bituminous:

Whose properties range from those of lignite to those of bituminous coal and are used primarily as fuel for steam-electric power generation. Sub-bituminous coal has a higher heating value than lignite. Most sub-bituminous coal is at least 100 million years old. Ranking below bituminous is sub-bituminous coal with 35-45 percent carbon content and a heat value between 8,300 and 13,000 BTUs-per-pound. Although its heat value is lower, this coal generally has a lower sulfur content than other types, which makes it attractive for use because it is cleaner burning [29].

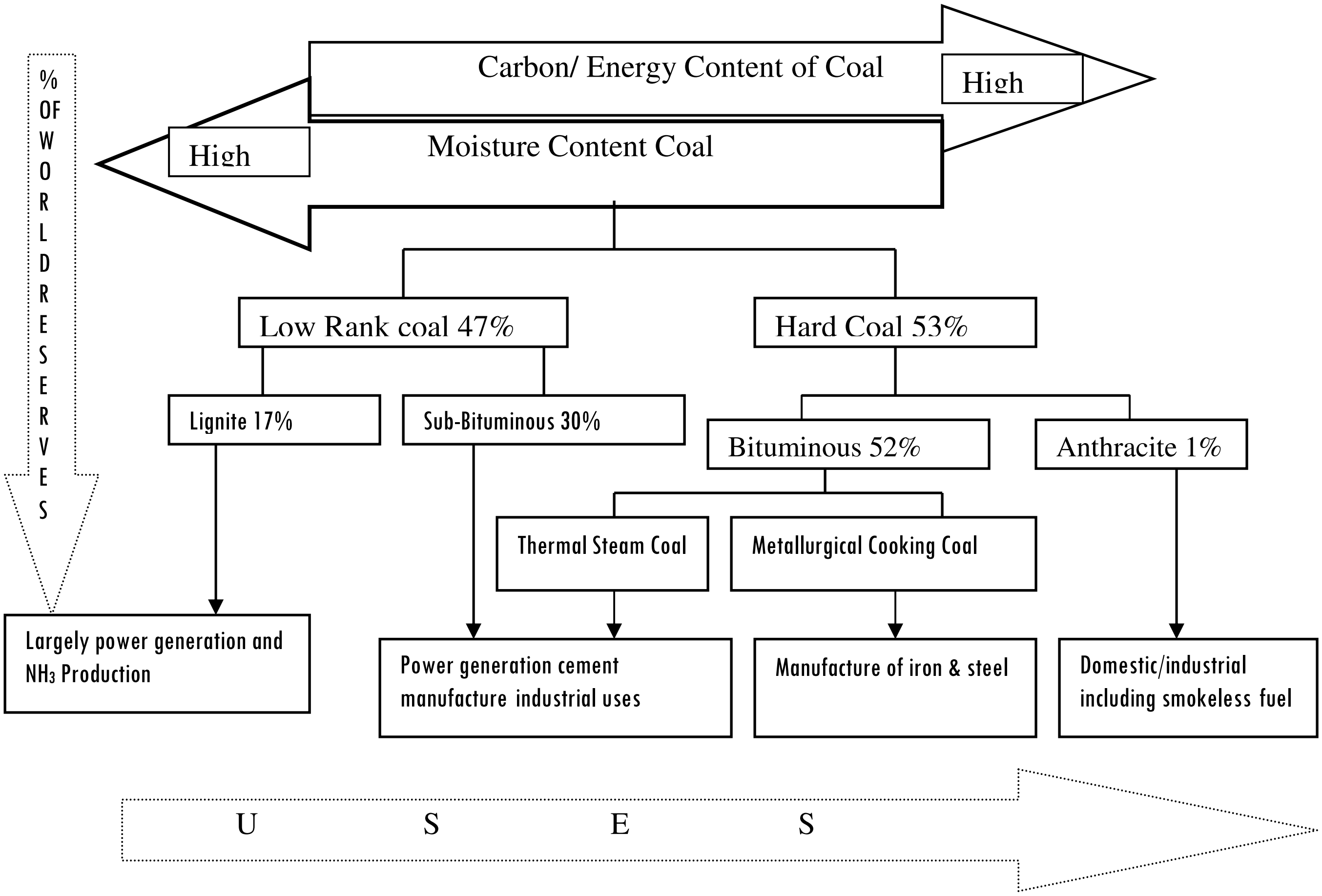
2.3.3. Bituminous coal:

Bituminous coal is a dense coal contains 45 to 86 percent carbon, and has two to three times the heating value of lignite (10,500 to 15,500 BTUs-per-pound). It was formed under high heat and pressure, and is used to generate electricity and is an important fuel and raw material for the steel and iron industries [32].

2.3.4. Anthracite:

Anthracite is a hard, compact variety of mineral coal that has a high luster. It contains the fewest impurities of all coals. It is the highest of the metamorphic rank, in which the carbon content is between 86 and 98 percent. The term is applied to those varieties of coal which do not give off tarry or other hydrocarbon vapours when heated below their point of ignition. Anthracite ignites with difficulty and burns with a short, blue, and smokeless flame. For this reason, anthracite has been the preferred coal for use as a domestic fuel [32].

Figure 2: Coal Ranks, Reserve and Applications [32]



2.4.Coal Reserves, Mining and Processing

2.4.1. World Coal Reserves

Coal is the world's most abundant, safe, secure, clean and cost effective fossil fuel.

- **Abundant-** extensive reserves of coal are present in many countries: coal is mined in more than 50 countries;
- **Safe-** coal is stable and hence the safest fossil fuel to transport, store and use;
- **Secure-**abundant reserves mean that coal users are guaranteed security of supply at competitive prices; hence electric supplies for industrial and domestic use are assumed;
- **Clean**-using current technologies, coal can now be burnt cleanly throughout the world;

- **Cost-effective**- globally coal is a competitive fuel for the generation of electricity, without which modern life would be virtually impossible. It is one of the major energy sources for power generation worldwide [32].

At current production levels, known coal reserves are forecast to last over years- significantly longer than known reserves of oil or gas. However, all fossil reserves are finite- they need to be used as efficiently and as commercially possible in order to conserve valuable reserves [8].

When scientists estimate how much coal, petroleum, natural gas, or other energy sources they use the term reserves. Reserves are coal deposits that can be mined using today's mining methods and technology. Coal resources are available in almost every country worldwide, with recoverable reserves in around 70 countries. Total recoverable reserves of coal around the world are estimated at 909064 million tons enough to last approximately 200 years at current consumption levels (Table 1).

Table 1: World Proved Reserves[3] at end 2005 [8]

Million Tons			
Proved coal Reserves	Anthracite and bituminous	Sub-bituminous and Lignite	Total
TOTAL WORLD	478771	430293	909064

These figures do not take into account the coal resources that:-

- may be proved by on-going exploration;
- will become accessible as further improvements are made in mining technology; and
- will become commercial through the increased use of presently uneconomic lower grade coals;

Historically estimates of world recoverable coal reserves, although relatively stable, have declined gradually from 1,174 billion tons at the beginning of 1990 to 1,083 billion tons in 2000 and 1,001 billion tons in 2003[19].

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[3] Proved reserves of coal - Generally taken to be those quantities that geological and engineering information; indicates with reasonable certainty can be recovered in the future from known deposits under existing economic and operating conditions;

2.4.2. Coal Mining

Modern mining methods allow to easily reach most of coal reserves. Due to improved mining technology, the amount of coal produced by one miner in one hour has been increased more than tripled since 1978. Depending on the amount of ground cover or overburden, the coal can be mined by the surface mining (complete removal of overburden) or the deep (underground mining.) method [32].

Factors for selection of the mining methods

1. occurrence characteristics of minefield, such as boundary and depth of deposit;
2. physical- mechanics properties of coal seam and surrounding strata;
3. hydro geological conditions;
4. Geological elements, including relative mining cost, and productive capacity required.

2.4.2.1. Surface Mining

Surface mining also known as opencast or open cut mining is only economic when the coal seam is near the surface. This method recovers a higher proportion of the coal. It is used when a coal seam is relatively close to the surface, usually within 61meters; surface mining is less expensive than underground mining. In surface mining giant machines remove the top-soil and layers of rock to expose large beds of coal. Once the mining is finished, the dirt and rock are returned to the pit, the topsoil is replaced, and the area is replanted. The land can then be used for croplands, wildlife habitats, recreation, or offices or stores [28].

2.4.2.2. Underground Mining

Underground mining sometimes called deep mining is used when the coal is buried several hundred meters below the surface. To remove coal in underground mines, miners ride elevators down deep mine shafts where they run machines that dig out the coal. In underground mining, workers and machinery go down a vertical "shaft" or a slanted tunnel called a "slope" to remove the coal, mine shafts may sink as much as 305 meter deep [22].

2.4.3. Coal Processing

To produce its maximum heat, coal must be converted to coke. Coke is nearly-pure carbon. The coke-making process is classified as the recovery method or the non-recovery method. The coal tar, smoke, gases, and volatiles that are released can be "recovered" or left to the winds (non-recovery). After the coal has been coked in this oven, it is removed and quenched with water to stop the oxidation process. The major use for coke is for fuel in iron and steel furnaces. Coke is very porous and lightweight, much like a sponge [32].

Coke is a solid carbonaceous residue derived from low-ash, low-sulfur bituminous coal from which the volatile constituents are driven off by baking in an oven without oxygen at temperatures as high as 1,000 °C (1,832 °F) so that the fixed carbon and residual ash are fused together. Coke is used as a fuel and as a reducing agent in smelting iron ore in a blast furnace. Coke from coal is grey, hard, and porous and has a heating value of 24.8 million Btu/ton (29.6 MJ/kg). Byproducts of this conversion of coal to coke include coal tar; ammonia, light oils, and "coal-gas" Coal processing include the coal preparation and conversion activities [32].

2.4.3.1. Coal Conversion

Coal conversion activities develop processes to convert coal into products that substitute for those derived from oil and natural gas including:-

- Crude oil;
- distillates;
- Chemical feedstock;
- Gas and other by- products

The liquefaction and gasification activities address the development of these products and their use in the market.

2.4.3.2. Coal Preparation

Coal as it emerges from mine, known as runoff- mine (ROM) coal, often contains unwanted impurities such as rock, clay and dirt and comes in a mixture of different-sized fragments. However, coal users need coal of a consistent quality. Coal preparation also known as coal beneficiation or coal washing, refers to the treatment of ROM coal to ensure a consistent quality and to enhance its suitability for particular end-uses by removing the impurities, or non – combustibles from a coal to produce a uniform, high quality, marketable fuel. The primary function of coal preparation facilities is, therefore, to deliver a finished coal product that has been custom prepared in terms of quality [21].

The type and degree of preparation are dictated by the individual user, or market, in the form of its clean coal specifications. The major factors that should be considered during coal preparation (not order of priority) are:-

- Economics of the operation;
- Characteristics of the particular coal being mined;
- Market specification;
- Environmental effects;
- Principles and applications of available coal preparation technology;

These considerations help determine what role the different unit operations will play in the overall coal cleaning scheme, generally coal cleaning operations can be grouped as chemical and physical cleaning processes (oxydesulfurization or basic reagent improve organic sulfur removal). The physical unit operations employed in coal cleaning includes size reduction, sizing, dewatering and/or drying.

2.4.3.3. Transporting Coal

After coal is mined and processed, it is ready to be shipped to market. The cost of shipping coal can cost more than the cost of mining it. Most coal is transported by train, but coal can also be transported by barge, ship, truck, and even pipeline. It is cheaper to transport coal on river barges, but barges cannot take coal everywhere that it needs to go. If the coal will be used near the coal mine, it can be moved by trucks and conveyors. Coal can also be crushed, mixed with water, and sent through a "slurry" pipeline. Sometimes, coal-fired electric power plants are built near coal mines to lower transportation costs [21].

2.5.Coal Application, Production and Consumption

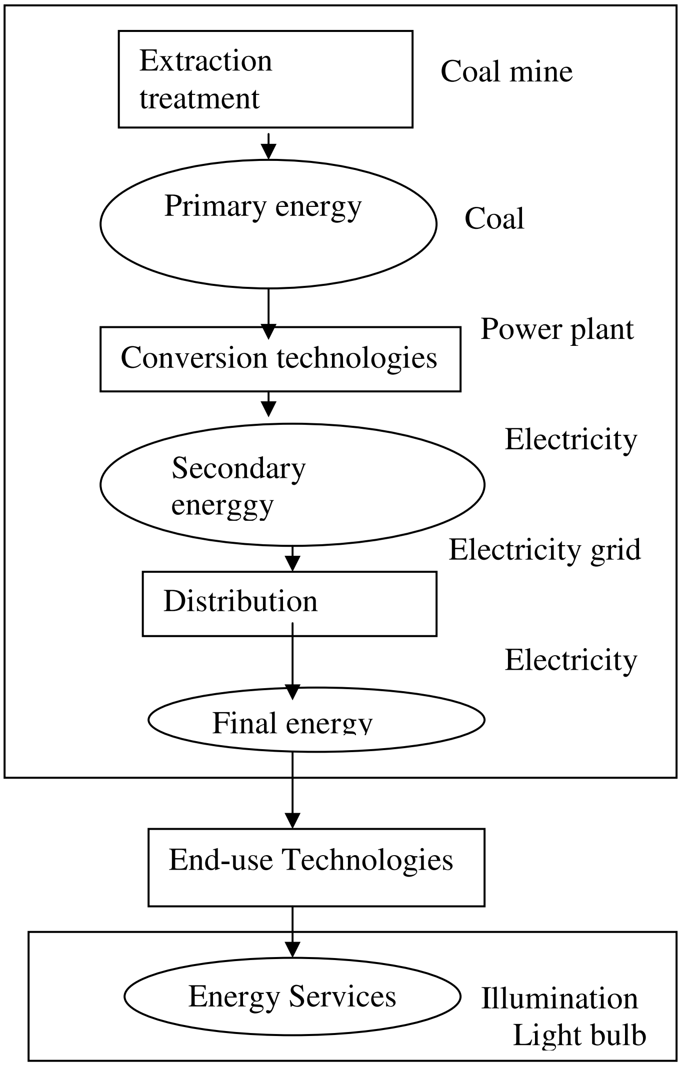
2.5.1. Application of Coal & Coal Based Products

Coal has a multidimensional uses worldwide; as direct application (electricity generation, steel production, cement manufacturing and source of energy for household) and feedstock for different chemical industries after undergoing through a gasification process.

2.5.1.1. For Electric Power Generation

Coal has covered currently about 40 % of the world's electricity generation. And many developed and developing countries are using coal as a reliable source or electricity generation. Besides electric utility companies, industries and businesses with their own power plants use coal to generate electricity, power plants burn coal to make steam. The steam turns turbines which generate electricity (Figure 3).

Figure 3: Energy Chain from Extraction to Energy Services [27]



2.5.1.2. For Making Steel

Coal is baked in hot furnaces to make coke, which is used to smelt iron ore into iron needed for making steel. It is the very high temperatures created from the use of coke [coke definition 2.4.3] that gives steel the strength and flexibility for products such as bridges, buildings, and automobiles. Coal is indispensable for iron and steel production (70% steel production comes from blast furnace using coal and coke) [21].

2.5.1.3. Direct application of coal

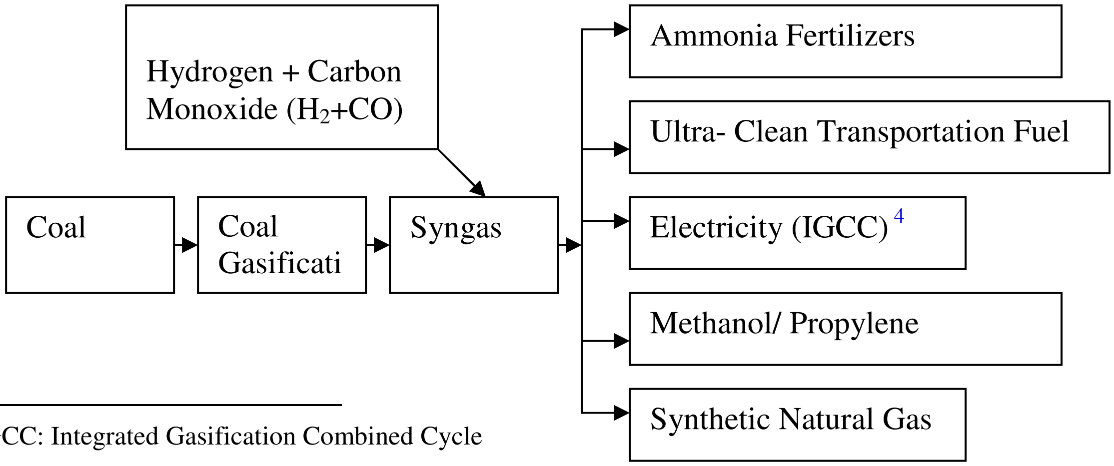
Coal can be used as source energy for household and small-scale industries (industrial processes heating and household for heating and cooking) after it is processed to a coal briquette. Coal can be used as an important substitute energy source in industries. Many industries use one of the petroleum products as a possible energy source beside electricity. For example in Ethiopia cement, metal and other industries spend considerable amount of their capital for the purchase of fuel, they can be the major possible users of the product among other industries [21].

2.5.1.4. As a Feedstock for Different Chemical Industries

Coal is also used as a feedstock in different industries like brick, limestone and other industries to make their products. Separated ingredients of coal (such as methanol and ethylene) are used in making plastics, propylene gas, tar, synthetic fibers, Ammonia/ fertilizer, Hydrocarbons and medicines.

The common and first step to produce most coal products is the gasification of coal. There are different types of coal gasification depending on the quality of coal [Figure 5] and its simplified form is represented in Figure 4. After undergoing through a gasification process to produce synthesis gas (H_2 and CO), coal can be used as a feedstock for the production of different chemicals. The following are some of the chemicals, which can be produced from coal (synthesis gas).

Figure 4: Simplified Form of Coal Gasification [6]



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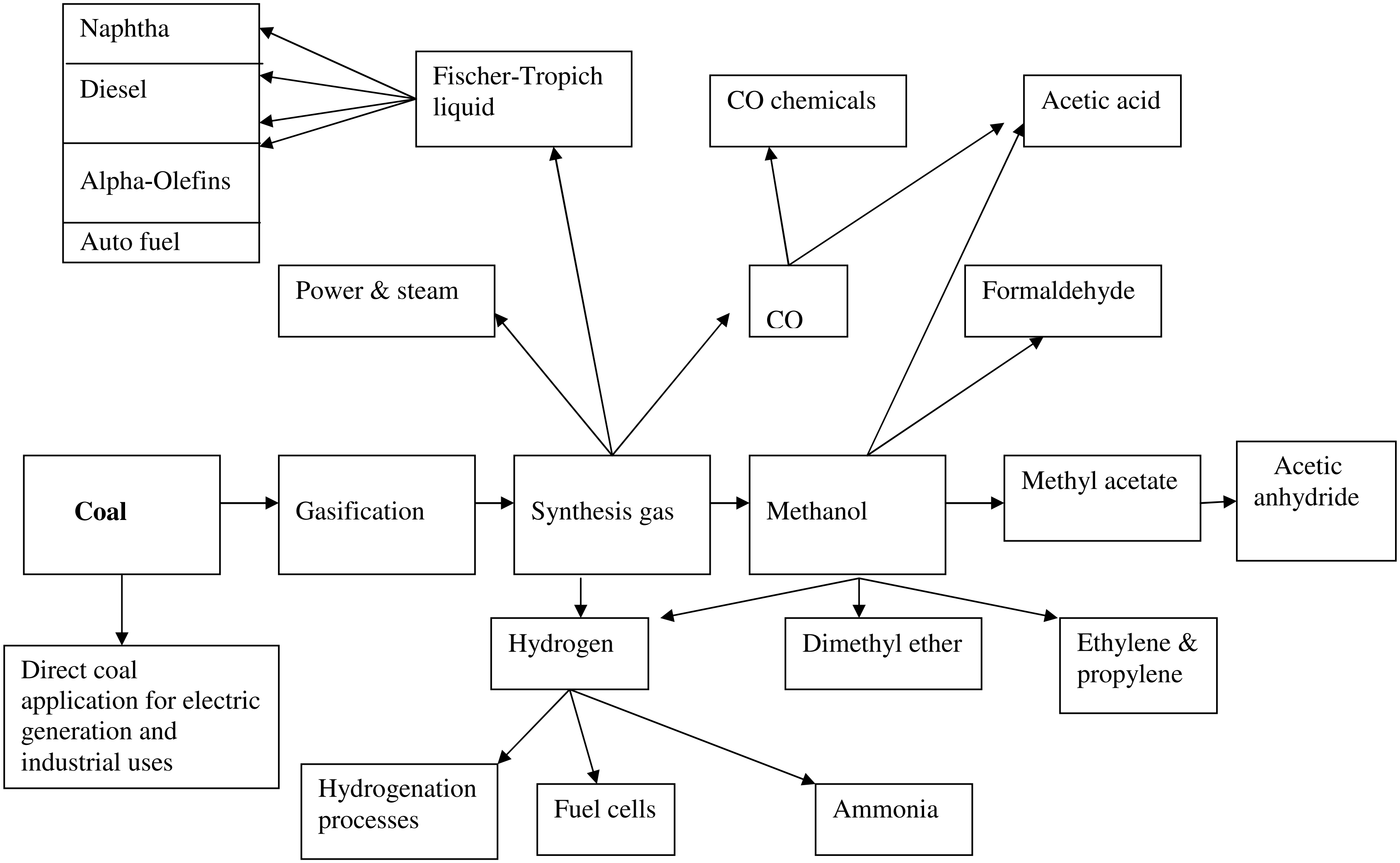
[4] IGCC: Integrated Gasification Combined Cycle

Figure 5: Co-production Potential from Coal [6]



2.5.1.5. Other Applications

2.5.1.5.1. Humic Acid Making

At present, the products of humic acid amount to more than a hundred sorts and are widely used in such lines as agriculture, medicine, machinery building, paper making, dyeing, food- staff, metallurgy, rubber, leather and ceramics etc. and playing an important role in industrial and agricultural production. The mined lignite, after drying, crushing, calcium-separating and deashing, can be used as raw material for making of verified humic acids [32].

2.5.1.5.2. Active Carbon Making

Active carbon is widely used in fields of environmental protection food- staff, medicine and chemical industries. Active carbon can be produced from lignite or long flam coal by certain production processing.

2.5.1.5.3. Building Materials (Coal Ash and Slag)

In many coal rich countries the high amount of ash from coal-based industries is being a menace to the environment, large amount of area is needed to dump the ash or some industries that could utilize it. The hand picked waste and the slag from furnace and boiler of the fertilizer factory and power plant can be mixed with clay and additive agent to make various building materials through certain productive processing that reduces the cost of building material and is a good practice for multipurpose utilization [4].

2.5.1.5.4. Application of by products

- Sulpphur is raw material for production of sulphuric acid
- Intermediate product ammonia can be used for production of nitric acid and ammonium nitrate
- Methyl alcohol, formaldehyde, acetic acid etc can be produced from the syngas of chemical fertilizer production
- The fly ash discharged from gasification until can be used to produce activated carbon that is used for adsorbing agent

2.5.1.6. For Export

Coal can be exported as any commercial goods to earn foreign exchange; Table 2 shows the major coal exporter countries from the world in 2005 and Table 3 shows the major coal importers in the same year.

Table 2: Top World Coal Exporters (2005) [8]

Country	Total (MT)	Steam(MT)	Coking(MT)
Australia	231	106	125
Indonesia	108	89	19
Russia	76	67	12
South Africa	73	72	1
PR China	72	66	6
Colombia	56	55	0.1
USA	45	19	26
Canada	28	1	26
Poland	21	18	3

Table 3: Top World Coal Importers (2005) [8]

Country	Total (MT)	Steam(MT)	Coking(MT)
Japan	178	114	63
Rep of Korea	77	56	21
Chinese Taipei	61	57	5
UK	44	37	7
Germany	38	31	7

2.5.2. Coal Production

Coal production is the amount of coal mined and taken to market. Over 4970 MT of hard coal is currently produced. Coal provides 25% of global primary energy needs (Figure 6) and generates 39.8% of the world's electricity. Total Global Hard Coal Production in 2005 was 4973 MT a 7.4% increase in production over the previous year & 78% growth over the past 25 years. 2004, 4631 MT in 1981, 2796 MT, Total Global Brown Coal/Lignite Production was 905 MT in 2005 and 893 MT in 2004, brown coal production increased by 1.4% in 2005 [32].

Table 4: World Coal Production*[5] [8]

Year	2000	2001	2002	2003	2004	2005	Change 2005 over 2004
Total World in Million tons	4606.2	4819.4	4849.9	5179.7	5577.9	5852.5	0.052106

The largest coal producing countries are not confined to one region. The top five producers are China, USA, India, Australia and South Africa. Much of global coal production is used in the country in which it was produced; only around 16% of hard coal production is destined for the international coal market. According to world energy council global coal production is expected to reach 7000 MT in 2030 with China accounting for around half the increase over this period. Steam coal production is projected to have reached around 5200 MT, coking coal 620 MT, and brown coal 1200 MT [32].

Table 5: Top Ten World Hard Coal Producers (2005) [32]

China	2226 MT	Russia	222 MT
USA	951 MT	Indonesia	140 MT
India	398 MT	Poland	98 MT
Australia	301 MT	Kazakhstan	79 MT
South Africa	240 MT	Colombia	61 MT

2.5.3. Coal Consumption

Coal plays a vital role in power generation and this role is set to continue. Coal currently fuels 39.8 % of the world's electricity (Figure 6) and this proportion is expected to remain at similar levels over the next 30 years. Table 6 summarizes the world coal consumption from 2000 to 2005.

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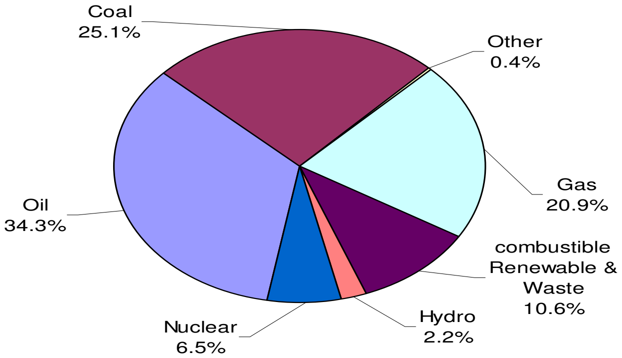
*[5] Commercial solid fuels only, i.e. bituminous coal and anthracite (hard coal), and lignite and brown (sub-bituminous) coal

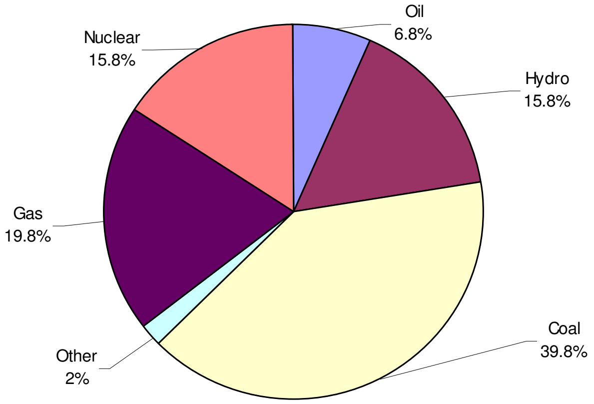
Figure 6: World Primary Energy Consumption [32]

a. Total world primary energy consumption (% by fuel-2004)



Note: Other includes geothermal, solar, wind, heat etc.

b. Total World Electricity Generation (% by fuel 2004)



Note: Other includes solar, wind, combustible renewable, geothermal & waste

Table 6 : World Coal Consumption (2000-2005) [32]

Coal: Consumption *[6] Million tons	2000	2001	2002	2003	2004	2005	Change 2005 over 2004
TOTAL WORLD	2360.9	2381.3	2433.5	2629.2	2798.9	2930	0.049622

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[6] * Commercial solid fuels only, i.e. bituminous coal and anthracite (hard coal), and lignite and brown (sub-bituminous) coal

According to WCI consumption of steam coal is projected to grow by 1.5% per year over the period 2002-2030. Lignite, also used in power generation, will grow by 1% per year. Demand for coking coal in iron and steel production is set to increase by 0.9% per year over this period [32].

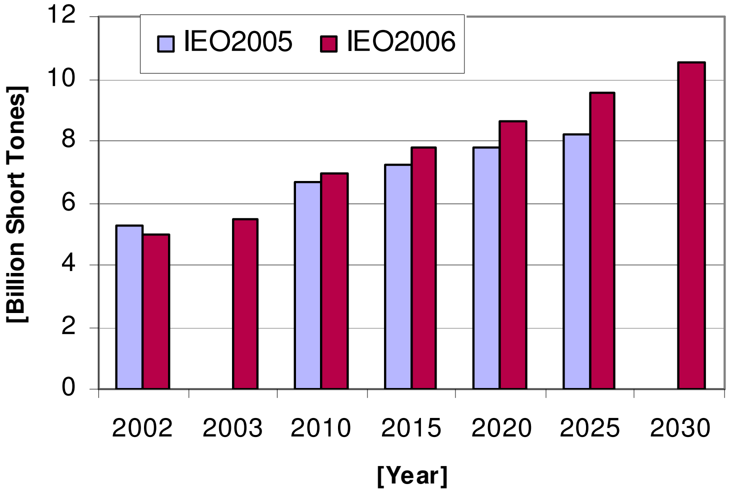
The biggest market for coal is Asia, which currently accounts for 56% of global coal consumption; although China is responsible for a significant proportion of this. Many countries do not have natural energy resources sufficient to cover their energy needs, and therefore need to import energy to meet their requirements. Japan, Chinese Taipei and Korea, for example, import significant quantities of steam coal for electricity generation and coking coal for steel production [32].

It is not just a lack of indigenous coal supplies that prompts countries to import coal but also the importance of obtaining specific types of coal. Major coal producers such as China, USA and India, for example, also import quantities of coal for quality and logistical reasons.

Coal use worldwide increases by 2.4 billion tons between 2003 and 2015 and by another 2.7 billion tons between 2015 and 2030. In this year's outlook for coal, nearly all regions of the world show some increase in coal use. The IEO2006 projection for world coal use in 2025 is 16 percent higher (on a tonnage basis) than in IEO2005 (Table 7). Consequently, coal's share of total energy use rises from 24 percent in 2003 to 27 percent in 2030 (Figure 7), and world coal consumption continues to exceed world natural gas consumption throughout the projections.

Table 7: Projections for World Coal Consumption, 2002-2030 [8]

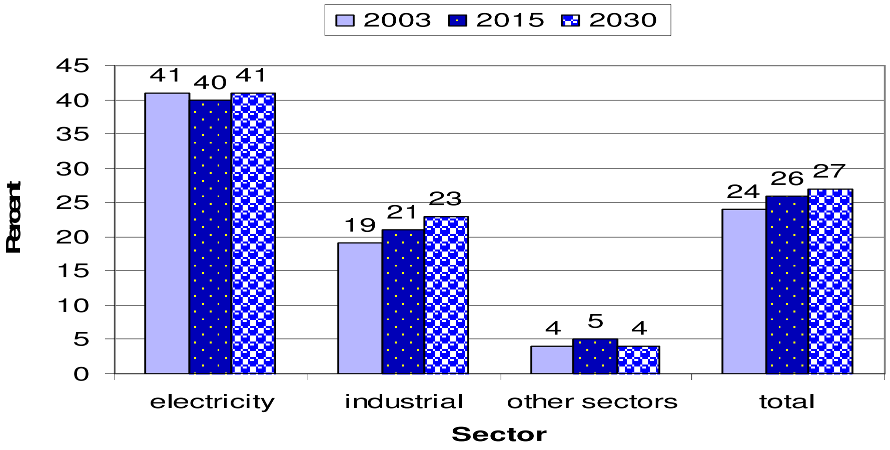
Year	Billion tons	
	IEO2005	IEO2006
2002	5.262	5
2003		5.4393
2010	6.67	6.956
2015	7.245	7.792
2020	7.767	8.642
2025	8.226	9.558
2030		10.561



2.5.4. World Coal Markets

In the IEO2006 reference case, world coal consumption nearly doubles from 2003 to 2030, with the non-OECD countries accounting for 81 percent of the increase.

Figure 7: Coal Share of World Energy Consumption by Sector [32]



2.6. Coal and the Environment

Environmental laws and modern technologies have greatly reduced coal's impact on the environment. Without proper care, mining can destroy land and pollute water. Today, restoring the land damaged by surface mining is an important part of the mining process. Because mining activities often come into contact with water resources, coal producers must also go to great efforts to prevent damage to ground and surface waters.

The coal industry has found several ways to reduce sulfur, nitrogen oxides, and other impurities from coal. They have found more effective ways of cleaning coal before it leaves the mine, and coal companies look for low-sulfur coal to mine. Power plants use "scrubbers" to clean sulfur from the smoke before it leaves their smokestacks. In addition, industry and government have cooperated to develop "Clean Coal Technologies" that either remove sulfur and nitrogen oxides from coal, or convert coal to a gas or liquid fuel. The scrubbers and NO_x removal equipment are also able to reduce mercury emissions from some types of coal [8].

2.6.1. Coal Burning and the Environment

There are a number of pollutants (including trace elements and fine particulates) emitted from coal burning. Trace elements, such as mercury, lead beryllium, arsenic, fluorine, cadmium and selenium, may be emitted as a result of the inorganic mineral composition of coal. Fine particulates (soot and fly ash less than 3- microns in size) may be a health hazard because; in contrast to coarse particulate (3- microns or larger), they bypass the body's respiratory filters and penetrate deeply into the lungs. In addition to their own innate toxicity, their porous character enables them to act as a transport mechanism for more toxic substances that otherwise might have been filtered in their natural states [32].

Combustion of coal, like any other fossil fuel, produces carbon dioxide (CO_2) the main greenhouse gas that is linked with global warming, and nitrogen oxides (NO_x) along with varying amounts of sulfur dioxide (SO_2) and mercury, that can pollute the air and water, depending on where it was mined. Sulfur dioxide reacts with oxygen to form sulfur trioxide (SO_3), which then reacts with water to form sulfuric acid. The sulfuric acid is returned to the Earth as acid rain.

Emissions of nitrogen oxide help create smog, and also contribute to acid rain. Mercury that is released into the air eventually settles in water. The mercury in the water can build up in fish and shellfish, and can be harmful to animals and people who eat them. Coal mining and abandoned mines also emit methane, another cause of global warming. Since the carbon content of coal is much higher than oil, burning coal is a more serious threat to the stability of the global climate, as this carbon forms CO_2 when burned. Many other pollutants are present in coal power station emissions, as solid coal is more difficult to clean than oil, which is refined before use. To eliminate CO_2 emissions from coal plants, carbon capture and storage can be used [5].

Coal and coal waste products including fly ash, bottom ash, boiler slag, and flue gas desulphurization contain many heavy metals, including arsenic, lead, mercury, nickel, vanadium, beryllium, cadmium, barium, chromium, copper, molybdenum, zinc, selenium and radium, which are dangerous if released into the environment. Coal also contains low levels of uranium, thorium, and other naturally-occurring radioactive isotopes whose release into the environment may lead to radioactive contamination. While these substances are trace impurities, enough coal is burned that significant amounts of these substances are released, resulting in more radioactive waste than nuclear power plants.

The coal industry's most troublesome problem today is removing organic sulfur, a substance that is chemically bound to coal. All fossil fuels, such as coal, petroleum, and natural gas, contain sulfur. When these fuels are burned, the organic sulfur is released into the air where it combines with oxygen to form sulfur dioxide. Sulfur dioxide is an invisible gas that has been shown to have adverse effects on the quality of air we breathe. It also contributes to acid rain; an environmental problem that many scientists think adversely affects wildlife (especially fish) and forests.

2.6.2. Environmental Problems Associated With Coal Production

The chief environmental problems of coal production include:-

- acid mine drainage;
- land subsidence;
- denuded lands;
- soil erosion sedimentation;

A major problem facing policy makers is that some of these effects cannot be reduced in an economically feasible manner, further, in the eyes of some, the internal incentives to reduce damage to surface productivity or waste quality appears to be modest, given existing surface values and current reclamation costs.

2.7. Energy Resource in Ethiopia

As can be seen in table Ethiopia has substantial energy resources consisting mainly of biomass, hydropower, geothermal and fossil fuels (especially natural gas and coal). Other renewable energy sources such as wind and solar energy are also available in the country. Although currently dominated by traditional biomass consumption, other energy sources such as hydropower and natural gas can potentially offer the nation for major social and economic development opportunities.

Table 8: Ethiopian Indigenous Energy Resources [17]

Resource	Unit	Exploitable Reserve	Exploited Percent
Hydropower	MW	30,000	<3%
Solar/day	KWh/m^2	4 - 6	~0%
Wind Speed	m/s	3.5 - 8	~0%
Geothermal	MW	1070	~0%
Wood	Million tons	1120	50%
Agricultural waste	Million tons	15-20	30%
Natural gas	Billion m^3	113	0%
Coal[7]	Million tons	96.3	0%

According to the Ethiopian Environmental Protection Authority (EPA)state of the environment report 2002, much of the energy needs of the country(77%) is met from fuel wood, while animal dung, crop residues, Liquid Petroleum Gas, charcoal, hydropower, petroleum and oil cover, 7.7,8.7,0.06,1.55,1.0,0.05, and 4.8 percent respectively. This shows that 95% of the energy consumed in the country originates from biomass energy source; the major source of electricity supplied in the country is from hydropower, which contributes about 90% of the total supply.

2.8. Coal Reserves and Occurrences in Ethiopia

The Non- renewable energy source coal (fossil fuel) is the primary source for many technological activities of the present day. It provides the major fraction of consumable energy and feedstock to industrial sectors, commercial organizations, as well as household entities all around the world. Exploration of coal in Ethiopia was started in the year 1935 at Nejo and Wuchale; however, it is not put into economic function. The present world wide energy crisis and increase in chemical fertilizer prices initiated the country to explore its own natural resources and promising reserves of coal have been explored in different parts of the country and now the government and many private investors are trying to use indigenous coal for different applications. The major

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[7] Recent data on the reserve shows more than this value

applications which have got greater attention are the utilization of coal as a raw material for the production of fertilizer and as source of energy for power and heat generation, especially in cement industries.

Extensive and intensive studies have been carried out at various scales from reconnaissance to detailed mapping and preliminary to detailed drilling net works to determine the amount of coal deposit in Ethiopia. Immense knowledge has been acquired about the geological distribution, geological setting, and geochemical characteristics of Ethiopian coals. More than 23 localities (occurrences) have been identified (further exploration may improve these figures) Table 9.

Table 9: Significant Coal Deposits in Ethiopia [6, 15, 24, 30, 31 and 25]

Locality	**Thickness (m)**	**Surface area (km^2)**	**Reserve in tons($x10^6$)**	**Administrative region**
Yayu			229[8]	
Moye	0.1-2.2	8-10	40-50	Illubabor
Dilbi	Varies from block to block(0.1-2.2)	4	20	Illubabor
Chilga	4.23 average	3.88	20	Gonder
Nejo	1.3	2.2	3	Wellega
Wuchale	0.5-1.5		3.3	Wollo
Mush Valley	1.75	0.15-0.26	0.8	Shoa

The coal reserves in different regions of the country are worth that can play an important role to facilitate the development of the national economy through industrial and agricultural development.

Due to driving forces, like the price rise in fertilizers and energy, the increase in demand, the growing awareness on the importance to utilize indigenous resources to secure sustainable development and to achieve the millennium development goals, Ethiopia has put forward a

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[8] The coal reserve is in a delimited area of only 41km^2 out of the possible 160km^2

measure to explore and utilize the basic local resource, among others coal has been attracting the government and intensive geological survey has been carried out since 1996**.**

There are occurrences in different parts of the country that assure the country has more coal reserve (Table 10) that could serve as a bridge to build sustainable agricultural and industrial development on rational use of these reserves, with acknowledgment of the clean coal technologies.

Table 10: List of Localities Known for Coal Occurrences in Ethiopia [24]

Location of Occurrence	**Administration Region**		**Location of Occurrence**	**Administration Region**
Arigo, Didessa, Nejo and Mendi	Wellega		Dessie, Merso and Wuchale	Wollo
Chida, Modjo, Meteso,Anchano, Soyoma, Sola, Jiren ,Lalo-Sapo and Waka	Keffa		Deridawa	Deridaw
Debrebrhan, debrelibanos, Fiche, Mojo, Muger and Ankober	Shoa		Halole	Sidamo
Kindo-Halale, Morka	Omo		Hunda , Dlesuma, Meiso	Hararge
Morka	Gamugofa		Adigrat	Tigray

As the exploration advances further, the number of coal occurrences increase from time to time. The geological survey of coal is not reached its end and the reserves discovered (explored) yet are not the last reserves. Some additional exploration still under way in the country has proven that there is coal and the coverage of the target area may be rationally expand, so the mineable resources will be increased accordingly that makes the service life of the mine longer.

Part Three: Discussion and Analysis

3. Coal as a Source of Energy in Metal Industries

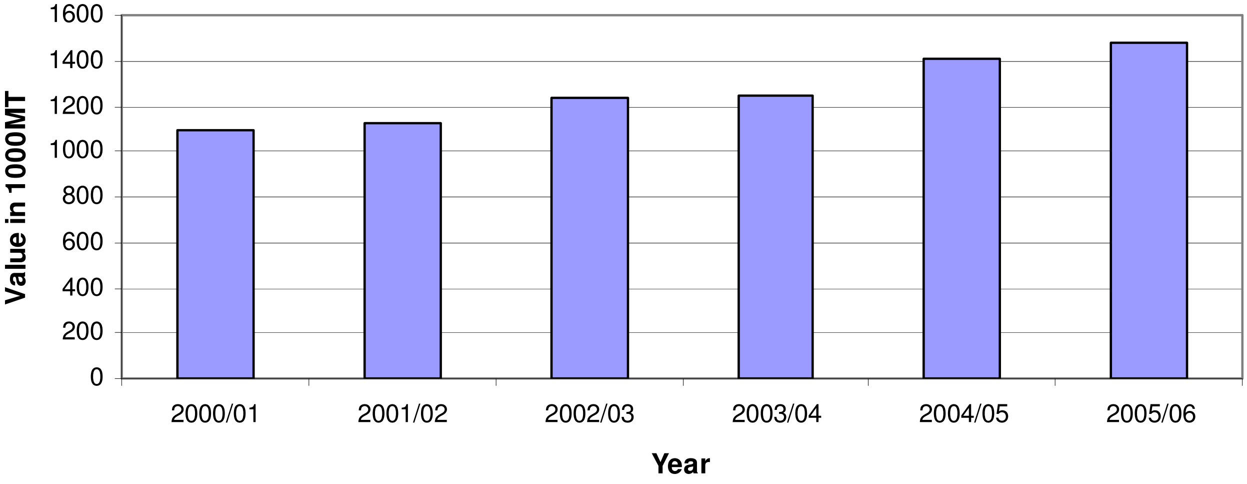
3.1. Current Consumption Patterns of Petroleum Products

As described in the literature review section of this thesis, coal has diversified applications world wide. Accordingly, the exploration for coal deposits is an integral part in the Ethiopia's effort to alleviate poverty, hence effective and rational utilization of the indigenous coal will have a great contribution to the sustainable development of the country.

The availability of energy at reasonable costs has always been a determinant condition of industrial growth, economic and social progress and the improvement of the standards of living of the population. Considering the amount of hard currency spent yearly by Ethiopia for petroleum products, it shares a major part of the total import bill of the country. The country is facing a major challenge to fulfill the huge and ever increasing demand of the imported sources of energy (petroleum products). And as indicated in (Table 11) the country's energy demand is increasing at a significant rate, meanwhile its price is increasing world wide.

Table 11: Volume of Imported Petroleum Products (2000/01-2005/06) In MT

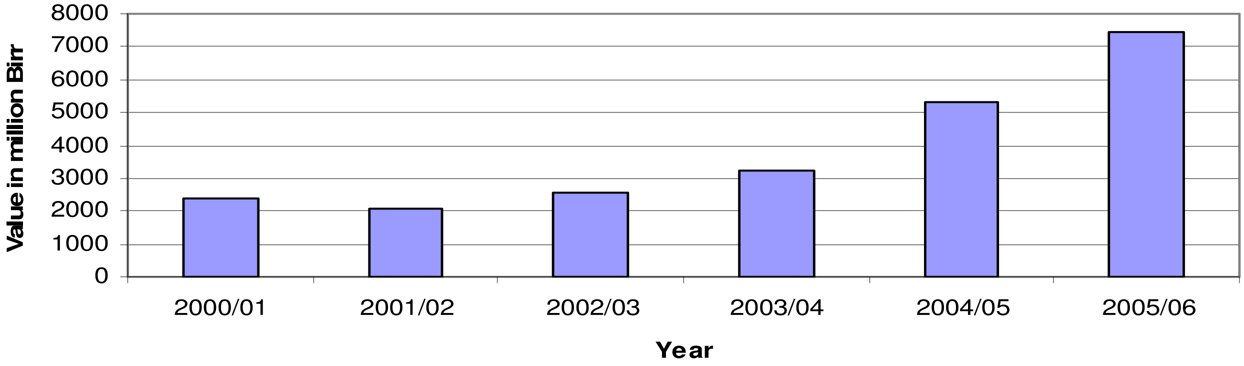
Year	**Products Type**					
	MGR	JET A-1	ADO	LFO	HFO	TOTAL
2000/01	129588	224536	620186	51852	69410	1095572
2001/02	132808	248711	622094	38412	80087	1122112
2002/03	148354	269210	679747	41698	93370	1232379
2003/04	130370	292766	687991	47121	89844	1248092
2004/05	147149	333079	771807	45109	109755	1406899
2005/06	137232	368670	811013	41385	116822	1475122



As can be seen in Table 12 the bill for the product is increasing from year to year due to the increase in price and demand.

Table 12: Value of Imported Petroleum Products (2000/01-2005/2006) In'000'Birr

Year	Products Type					
	MGR	JET A-1	ADO	LFO	HFO	TOTAL
2000/01	346,536	532,685	1,307,334	79,006	101,726	2,367,287
2001/02	291,310	498,491	1,109,177	56,666	109,076	2,064,720
2002/03	370,249	609,314	1,339,727	69,505	147,928	2,536,723
2003/04	411,304	825,219	1,737,682	86,589	156,234	3,217,028
2004/05	603,547	1,437,764	2,928,585	96,342	222,594	5,288,832
2005/06	703,403	2,180,230	4,076,946	131,130	338,701	7,430,410



Energy is closely linked to economic development and environmental quality. It is central to the country's economy as the demand for energy is related to economic growth and standards of living. During the period of 1995 to 2020, demand for energy world wide is forecasted to increase by around 65% equivalent to 2% per annum. Fossil fuels are expected to meet 5% of the additional energy demand [25].

As the prices of petroleum products increase in the global market nations are try to use coal as an alternative source, and the clean coal technologies is trying to develop mechanisms to reduce the negative environmental effects of coal use. The current situation in Ethiopia increase in energy demand, raise in price of petroleum products and its effect on the prices of other commodities are pushing the country to find alternative energy source options to secure sustainable development.

Coal is therefore, one of the most important mineral resources of the country to contribute significantly for the economic growth and to make Ethiopia self- reliant by substituting petroleum as a source of energy in industries.

The long-term economic development is focusing on keeping a continuous economic development by utilizing domestic resources and labour to promote a parallel development of agriculture and industry through the agricultural development lead industrial development (or industrialization with the development of agriculture as the lead).

Table 13 shows the petroleum product consumption by sector from 2001 to 2005; this data shows the share of the major economic sectors. The industry and construction sectors are the major consumers; from the industry sector cement, sugar and metal industries are leading ones, however considerable attempts are being undertaking to use coal as a source of energy in cement industries. The sugar industries are putting their efforts to develop bio-fuel sources from their by-products.

Table 13: Energy Consumption[9] by Sector (Fuel)

Year	Consumer	Agriculture	Industries	Construction	Mines	Water Resource	Ministries	EEPCO[10]	Defense	In.Org[11]	Transport	Others	Total
2001/02	Benzene	625.2	1514.4	1514.4	13.0	134.0	515.6	80.0	1350.7	91.3	2811.7	2811.9	**11462.2**
	Kerosene	14	1097.9	1097.9	0.0	0.0	37.2	0.0	16.0	3.0	76.0	1381.8	**3723.8**
	Diesel oil	13530.4	28735.9	28735.9	5555.0	3852.0	6497.4	8143.0	13347.0	2150.3	24567.7	22914.6	**158029.2**
	Fuel oil	0.0	112593.3	112593.3	599.0	0.0	0.0	0.0	0.0	0.0	2.0	1108.0	**226895.6**
	LPG[12]	8.0	217.0	217.0	0.0	0.0	3.0	0.0	0.0	17.0	0.0	2507.9	**2969.9**
	Lubricants	429.1	1490.8	1490.8	309.7	104.1	109.5	105.1	781.8	37.2	1433.8	1924.5	**8216.4**
	Jet fuel(A-1)	0.0	144.8	144.8	0.0	0.0	0.0	0.0	4316.9	24.0	53694.0	23041.2	**81624.7**
Total		**14865.7**	**145794.1**	**145794.1**	**6476.7**	**4090.1**	**7162.7**	**8328.1**	**19812.4**	**2322.8**	**82585.2**	**55689.9**	**492921.8**
2002/03	Benzene	543.2	1543.7	1543.7	52.0	72.0	896.8	45.0	1214.7	36.5	2616.8	2975.5	**11539.9**
	Kerosene	0.0	1017.6	1017.6	0.0	0.0	30.0	0.0	127.4	0.0	237.0	452.0	**2881.6**
	Diesel oil	13202.1	29607.3	29607.3	7662.3	2992.0	5836.5	17190.5	16594.8	2069.3	24066.5	25611.1	**174439.7**
	Fuel oil	0.0	108321.6	108321.6	132.0	0.0	162.0	930.9	1659.9	0.0	0.0	1592.9	**221120.9**
	LPG	8.0	250.0	250.0	0.0	0.0	4.0	0.0	0.0	16.0	0.0	253.1	**781.1**
	Lubricants	428.0	1513.2	1513.2	341.4	109.0	211.1	409.5	362.4	39.4	1590.7	2005.6	**8523.5**
	Jet fuel (A-1)	0.0	0.0	0.0	0.0	0.0	1.0	0.0	4334.1	0.0	64333.0	26042.2	**94887.3**
Total		**14358.3**	**142253.4**	**142253.4**	**8187.7**	**3173.0**	**7141.4**	**18575.9**	**24293.3**	**2161.2**	**92844.0**	**58932.4**	**514174.0**
2003/04	Benzene	368.5	1177.9	1177.9	23.0	56.0	621.1	50.0	1448.7	107.3	2671.9	2177.6	**9879.9**
	Kerosene	0.0	1456.9	1456.9	0.0	0.0	0.0	0.0	10	2.0	242.0	421.0	**3588.8**

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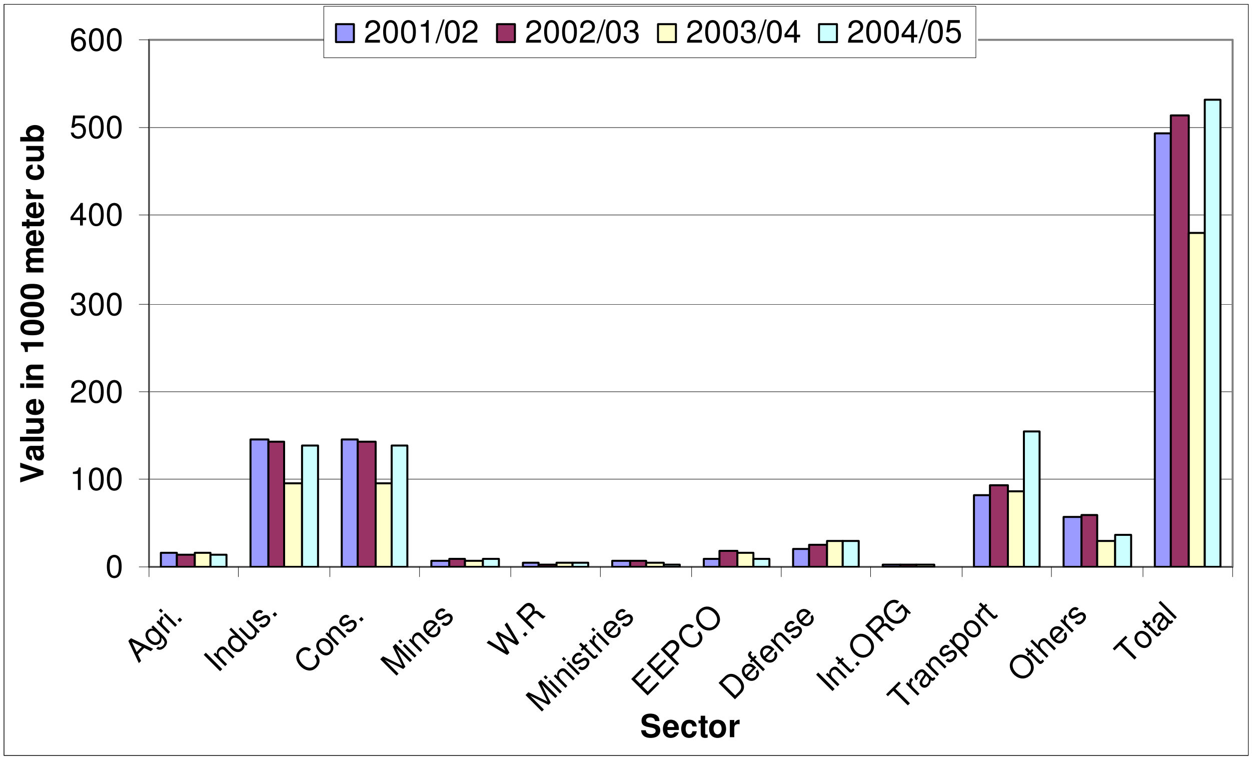
[9] Volume in meter cube except LPG in metric ton

[10] EEPCO: Ethiopian Electric Power Corporation

[11] In.Org: International Organization

[12] Liquefied Petroleum Gas

Year	Consumer	Agriculture	Industries	Construction	Mines	Water Resource	Ministries	EEPCO[10]	Defense	In.Org[11]	Transport	Others	Total
	Diesel oil	13872.9	27975.5	27975.5	6416.8	3294.0	4129.5	12326.8	19906.9	1500.7	27509.8	16017.0	**160925.4**
	Fuel oil	0.0	62382.3	62382.3	252.0	0.0	0.0	2239.2	0.0	0.0	6.0	583.6	**127845.4**
	LPG	49.0	316.0	316.0	0.0	0.0	0.0	0.0	0.0	26.0	0.0	205.0	**912.0**
	Lubricants	431.7	1415.8	1415.8	353.2	111.2	47.1	340.0	735.0	39.8	2274.1	1759.4	**8923.1**
	Jet fuel (A-1)	216.0	96.0	96.0	0.0	0.0	0.0	4.9	7090.5	0.0	52266.0	8271.5	**68040.9**
Total		**14938.1**	**94820.4**	**94820.4**	**7045.0**	**3461.2**	**4797.7**	**14960.9**	**29191.1**	**1675.8**	**84969.8**	**29435.1**	**380115.5**
2004/05	Benzene	302.0	1281.0	1281.0	0.0	55.0	504.0	55.0	1193.0	9.0	2020.0	5182.0	**11882.0**
	Kerosene	323.0	1357.0	1357.0	0.0	0.0	45.0	0.0	109.0	0.0	193.0	5204.0	**8588.0**
	Diesel oil	11661.0	30993.0	30993.0	7923.0	4419.0	2548.0	8143.0	18995.0	852.0	29622.0	21080.0	**167229.0**
	Fuel oil	180.0	102066.0	102066.0	286.0	0.0	0.0	231.0	431.0	0.0	16.0	1177.0	**206453.0**
	LPG	0.0	21.0	21.0	0.0	0.0	0.0	0.0	385.0	0.0	0.0	77.0	**504.0**
	Lubricants	388.0	1335	1335.0	121.0	105.0	23.0	86.0	878.0	17.0	1282.0	772.0	**6342.0**
	Jet fuel (A-1)	0.0	133.0	133.0	0.0	0.0	0.0	0.0	8353.0	144.0	120316.0	2199.0	**131382.0**
Total		**12958.0**	**137186.0**	**137186.0**	**8330.0**	**4579.0**	**3120.0**	**8515.0**	**30344.0**	**1022.0**	**153449.0**	**35691.0**	**532380.0**



3.2.Coal as Source of Energy for Metal Industries

The fast growth in construction industries in the country leads to high demand on metal products, as a result the number of metal producing industries in the country is growing from time to time, this increment in number and production volume in turn leads to increased demand and consumption in energy, particularly imported petroleum products.

As shown in Table 14 the energy demand of the selected industries is increasing from year to year, meanwhile the energy prices are increasing at alarming rate world wide, hence importing by more hard currency seriously affects the country's development strategy. Therefore, the country needs to search for other options to meet this energy demand and ensure sustainable economic development. But at the same time the environmental effect of the alternative source of energy needs to be considered. The major environmental negative effects of coal in this application are the release of significant amount of CO_2 and the disposal of ash and slag and the thermal pollution from these products.

In this thesis, use of indigenous coal in metal industries as substitution for the heavy fuel oil (furnace oil) and as initiation of effective allocation of scarce natural resource and management for sustainable development is demonstrated and the possible emissions are quantified.

Survey of energy consumption and demand is conducted for the following three metal industries:-

1. Ethiopian Iron and Steel Factory
2. Zuqalla Steel Rolling Mill Enterprise
3. Akaki Metal Products Factory

3.2.1. Selected Factories in Brief

3.2.1.1. Zuqalla Steel Rolling Mill Enterprise (ZuSRoM)

Zuqalla Steel Rolling Mill Enterprise which was established on the 27th of February, 1997 at Debrezeit is one of the largest manufacturers in Ethiopia. The factory has substantial contribution for the development of the construction industry of the country. The production process takes place off from the highest standard raw material, 100 square-sectioned billet of G-60 standard, and will be heated above 1400°C for the production of the reinforcement bars with required sizes. The main raw material is billet with G-60/G-40 standards, imported from different countries (Turkey, Russia/ Ukraine, Zambia, China etc), and the main products are reinforcement bars (round, smooth and ribs) of length 12m and different diameters, flat square and angle iron of various sizes. The production system of the factory is automatic continuous process, and uses one oil fire furnace with eight burners for heating and reheating of the billet materials.

3.2.1.2. Ethiopian Iron and Steel Factory (EISF)

Ethiopian Iron and Steel Factory is a state enterprise, which was established in 1959 is located about 20km south east of Addis Ababa. The factory is engaged in melting steel scraps in a 5(five) tons electric arc furnace for the production of pencil ingots. It is also engaged in the production and marketing (domestic market) of reinforcement bars (range ϕ6-32mm),iron nails, bed spring, galvanized fencing nets, barbed wires and other products from imported prime quality hard steel billets, low carbon wire rods and galvanized wires.

Most of the inputs (raw and processed materials) are imported (from Russia /Ukraine, Turkey, china, Italy and others), while iron scrap is locally collected or purchased from various sources in the country, heterogeneous in character. The following major input (raw materials) are:-

Direct	Processed
Billet	Different types of refractory bricks
Steel scrap	Dolomite powder
Low carbon wire rod	Ramming cement
Galvanized wire	Casting molds
Ferro-manganese	Mortar cement
Ferro-silicon	Electrodes, liquid soap, packaging paper, spare parts etc.

3.2.1.3. Akaki Metal Products Factory (AMPF)

Akaki Metal Products Factory is public enterprise which was founded in 1964 is located at Akaki some 22Km south of Addis Ababa. The factory is engaged in production and marketing (domestic market) of hot dip galvanized and corrugated proofing sheets, water pipes, rectangular hollows sections and round furniture and construction tubes and provides galvanizing services.

The Factory has two main production lines, corrugated galvanized steel sheet and galvanized steel pipe. The first line of production has two complete production lines (two furnaces) one line for stand by, while the second production line has only one line of production (one furnace). The factory has of total three similar furnaces except in size. The main products of the factory includes:-

- Corrugated galvanized steel sheets of different sizes(22,000MT per annum);
- Galvanized steel pipes of different sizes(12,000MT pipes per annum);
- Different Furniture's and structural pipes of different sizes;

For the production of these products the factory uses the following raw material inputs:

- Cold rolled steel sheets;
- Hot rolled steel strips;
- Cold rolled steel strips;
- Zinc ingot;

The factory also uses different chemicals in the production process, such as:-

- Ammonium chloride
- Hydrochloric acid
- Zinc ammonium chloride
- Caustic soda
- Sulfur
- Tin

For this analysis corrugated galvanized steel sheet production line is selected.

3.3. Energy Consumption Pattern of the Selected Industries

3.3.1. Fuel wood

Though it is difficult to obtain exact data on wood consumption of all industries, they use considerable amount of wood to heat the furnace during down time (maintenance & non-production times).

Factory	Wood Consumption(m^3)	Duration	
		For Non Production day down time in hours	During Maintenance down time in days
Ethiopian Iron and Steel Factory	10-20	3-4	3-4
Akaki Metal Products Factory			
Zuqalla Steel Rolling Mill Enterprise			

The factories use approximately, 10-20m^3 wood for 3-4 hrs during non- production time (all) and 3- 4 days continuously during down time for maintenance and other cases (Akaki Metal Products Factory).

3.3.2. Electric Power

As indicted in Table 14 though the volume differs, all factories use electric power for production. . Similarly, Ethiopian Iron and Steel Factory, uses more electric power energy for melting of metal scraps in the electric (induction) furnace. Akaki Metal Products Factory uses electric power to drive electrical equipments and machines (like pumps, motor etc)

3.3.3. Heavy Fuel Oil (Furnace Oil)

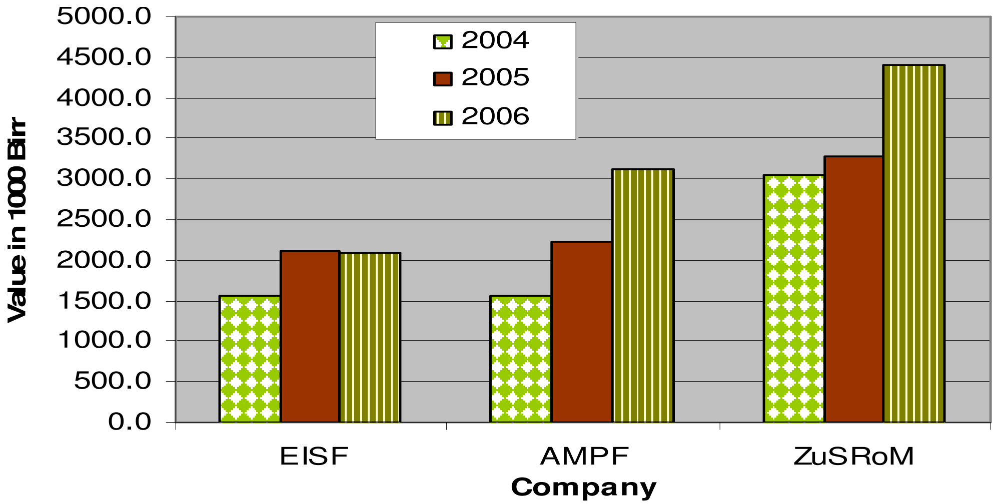
As it can be seen in Table 14 the major portion for energy demand in the metal industry is covered by Heavy Fuel Oil (HFO). It is the leading source of energy when compared to other sources of energy and petroleum products. The equipments (machines) which consume this fuel are the heating furnaces. Generally, there are three types of furnaces currently utilized by the selected industries.

a) the electrical induction furnace (Ethiopian Iron and Steel Factory);
b) heating furnace used to melt Zinc and lead(Akaki Metal Products Factory); and
c) heating furnace to heat and reheat the billet and ingot metals (Ethiopian Iron and Steel Factory and Zuakala Steel Rolling Mill Enterprise).

Table 14: Energy Consumption Patterns of Selected Metal Industries (2004-2006)

Company	2004			2005			2006		
	Heavy Fuel oil / Gasoline		Electric	Heavy Fuel oil / Gasoline		Electric	Heavy Fuel oil / Gasoline		Electric
	QTY (liter)	Value (Birr)	Value (Birr)	QTY (litter)	Value (Birr)	Value (Birr)	QTY (litter)	Value (Birr)	Value (Birr)
[12] EISF	674422.0	1551170.0	196690.0	664119.0	2109979.4	1966138.0	586984	2075838	422626.0
AMPF	674,308.0	1567,872.0	259,785.4	605,917	22,16792.6	312,628.7	871697	3119650	324,388.9
[13] ZuSRoM	1004861.0	3,053,342.0	533,270.3	665220.0	3,286,024.0	492,959.4	1480617	4,393,017.8	458,582.5

Figure 8: HFO Consumption of the Selected Metal Factories



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[12] Consumption of furnace oil 90litter per ton product(on average)
[13] Consumption of furnace oil 70 litter per ton product(on average)

3.4.Case Factory

For detail analysis, Akaki Metal products Factory is selected based on the following selection criteria:-

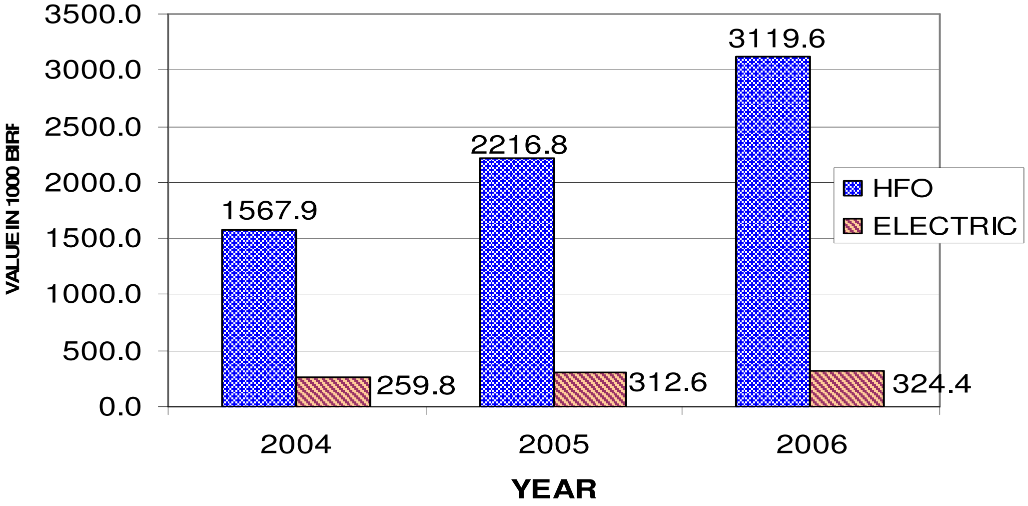
1. Energy demand (HFO) of the factories(based on the 3- years data, Table 14 and Figure 8) Akaki Metal Products Factory is second to ZUSROM;
2. technical applicability , the existing heating furnaces of the other factories are used to heat metals (ingot and billet) directly, which is difficult to heat the metal directly by coal at the operating temperature(1100-1200^{0}C), while the AMPF's furnace is used to melt Zinc and lead by indirect heating;
3. AMPF has three similar furnaces, with the same application(type);
4. the existing furnaces of AMPF are flexible to modify for combustion of coal(fluidized bed);
5. the potential of the AMPF' business line to grow in the country, as a result of the increase in the construction industry.

3.4.1. Energy Consumption of the factory (2004-2006)

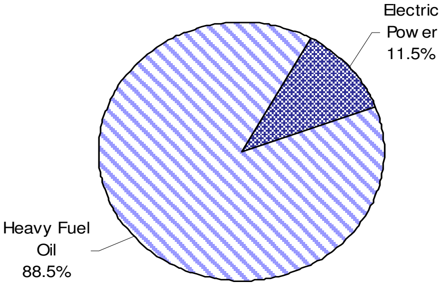
As can be seen in table 16, the major energy demand of the factory is covered by heavy fuel oil, electric power shares the rest, the energy consumption pattern of the factory for the last three years is shown in Figure 9.

Figure 9: Energy Consumption Pattern of Akaki Metal Products Factory.

a) Energy cost by type (2004- 2006)



b) Cost share in the three years



Energy cost by source(2004-2006)

The cost of Heavy Fuel Oil of the factory (Table 14) has increased by 29.3 percent in the period 2004- 2005 and 28.94 percent in 2005/2006.

3.4.2. Description of the Existing System

Looking at the current system of the corrugated steel sheet production, there are two production lines (one stand by) with oil fire (heating furnace with two burners) each. Firing is made by continuous supply of heavy fuel oil (source of energy Table 15) and air (oxidizer). This furnace is used to heat rectangular steel zinc pot, of 2434mm length, 1000mm depth, 1620mm width and weighs 4 tons. It is laid on a flat surface of the internal floor of the furnace.

Zinc and lead metal ingots are filled in to this pot and melt up to an operating temperature of 460-480^{o}C. Heat is supplied from one side of the short sides and circulates to the other two adjacent sides of the source and the exhausted gas exit directly in opposite side of the heat supply as can be seen [Annex (A)], both the longer sides are exposed to heating. Zinc is used to coat the product, while lead is used to keep the operating level of zinc (zinc floats due to density difference), to protect the pot from damage and to reduce zinc wastage.

Table 15: Properties of Imported Heavy Fuel Oil (Sample)

Property	ASTM/ IP Test Method	Limits	Lab test results	Reducibility
Specific Gravity @15-20°kg/m^3	D1298	0.890-0.960	0.9545	0.0015
Flash point (PMCC),°C	D93	Min. 60	76°C	
Sulphur, % wt	D1552	Max. 3	3.5	
Calorific value, BTU/Lb	ISO 8217	Min. 18500	18579.5(43.215971MJ/Kg[14]	
Kinematics Viscosity @122°F,CST	D445	Max. 180	130.5	
Pour point, °C	D97	Max.10	+3°C	6
Ash content, % wt	D482	Max. 0.05	0.002	0.005
carbon , %wt	D198	Max.10	9.7	1.85
Sediment by extraction,%	D473	Max.3	0.001	0.033
Water content, %	D95	Max.0.1	0.1	0.2
Water and sediment, %	D1796	0.5	0.1	

Operation System

The system is a continuous operation that load is supplied continuously and the production of the corrugated steel metal products is coated in the zinc pot. the factory operates 24 hours per day, three shifts, and 8 working hours each shift, the average production is 40 tons per day (24 hours),

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[14] Conversion factor BTU/Lb * 2326 =J/Kg

fuel consumption 2500litters per 40 tons production and the operating temperature ranges 400-500°C (460-480°C operating). For this thesis work all calculations and quantity determinations are based on burring of coal to produce 40 tons of corrugated steel sheets. And the system is considered steady state condition. For calculation and comparison of HFO fuel specification set by EPE is used and presented in Table 15.

3.5.System Selection Criteria

Coal can be used in the Case Factory, in two ways:

1. if coal is pulverized, it can be fired same manner as the fuel;
2. the furnace can be modified to fluidized bed , so that coal can be combusted;

Due to

1. technical applicability and flexibility of the current system for modification to fluidized bed ;
2. better heating efficiency and degree of emission control (discussed in the next topics)

Fluidized bed combustion is elected for the application of coal in the Case Factory for the selected operation.

3.5.1. Fluidized Bed Technology Description

In solid (coal)-gas (air) contacting equipment, the solids can exist in any of the following four conditions

1. **Static**: this is a dense bed of solids in which each particle rests upon another at essentially the settled bulk density of the solids those especially there is no relative motion among solid particles(tray dryer)
2. **Moving**: this is slightly expanded bed of solids in which the particles are separated only enough to flow one over another. In this case solids motion is achieved by either mechanical agitation or gravity force (rotary dryer with filter).
3. **Fluidized:** this is an expanded condition in which the solids particles are supported by drag forces caused by phase passing through the interstices among the particles at the some critical velocity. it is an unstable condition in that the superficial gas velocity upward is less than the terminal settling velocity of the solids particles, the gas velocity is not sufficient to entrain and convey continuously all the solids. At the same time, there exist, within the stream of gas,

eddies traveling at high enough velocities to lift the particles temporarily. Particles motion is continually upward and falling back; especially the solids phase and the gas phase are intermixing and together behave like a boiling fluid.

4. **Dilute:** this is a fully expanded condition in which the solids particles are so widely separated that they exert essentially no influence upon each other, commonly, this situation exists when gas velocity of the solids and the particles can be lifted and continuously conveyed by the gas however, this is not always true.

Many types of gas-solid reactions have been designed to allow motion of the solid relative to fixed walls of the reactors. This motion is desired for one or more of the following reasons:-

- to enhance heat transfer between the particle and the environment;
- to enable use of small particles;
- to facilitate continuous removal of ash and slag; and / or
- to accommodate size changes of the particles current with reaction;

The particle motion can be accomplished by purely mechanical means perhaps guided by gravity as a rotary cement kilns and fireplace grates. It is preferred to design where the particle motion as brought about through hydrodynamic forces that are generated by a fluid phase that also participates in the reaction. One of the most popular equipment for this purpose is the fluidized bed combustion system.

Fluidized-bed combustion evolved from efforts to find a combustion process able to control pollutant emissions without external emission controls (such as scrubbers). The technology burns fuel at temperatures of 1,400 to 1,700 °F (750-900 °C), well below the threshold where nitrogen oxides are formed (at approximately 2,500 °F (1400 °C)). The mixing actions of the fluidized bed results bring the flue gases into contact with a sulfur-absorbing chemical, such as limestone or dolomite. More than 95% of the sulfur pollutants in coal can be captured inside the boiler by the sorbent. The reductions may be less substantial than they seem, however, as they coincide with increases in carbon dioxide, nitrous oxide, and polycyclic aromatic hydrocarbons emissions. The three broad areas of application of fluidized-bed combustion are incineration, gasification, coal and municipal waste burring and steam generation [13].

3.6.Fluidized Bed Accessories

A fluidized-bed combustor is a furnace chamber whose floor is slotted, perforated, or fitted with nozzles. Air is forced through the floor and upward through the chamber. The chamber is partially filled with particles of coal, which will fluidize at an appropriate air flow rate. When fluidization takes place, the bed of coal expands (bulk density decreases) and exhibits the properties of a liquid. As air velocity increases, the particles mix more violently, and the surface of the bed takes on the appearance of a boiling liquid. Once the bed is fluidized, its temperature can be increased with igniters until a combustible material can be injected to burn within the bed. Proper selection of air velocity, operating temperature, and bed material will cause the bed to act as a chemical reactor.

The major parts of fluidized bed system are [Figure 10]:-

1. fluidized vessel(reaction vessel):
    a. fluidized bed portion;
    b. disengaging space or free board;
    c. gas distributor;

2. solids feeder or flow control;
3. solids discharge;
4. Dust separator for the exit gases , and gas supply(commonly air cyclones) and
5. Instrumentation, of course, is also an important consideration in designing of a fluidized bed system

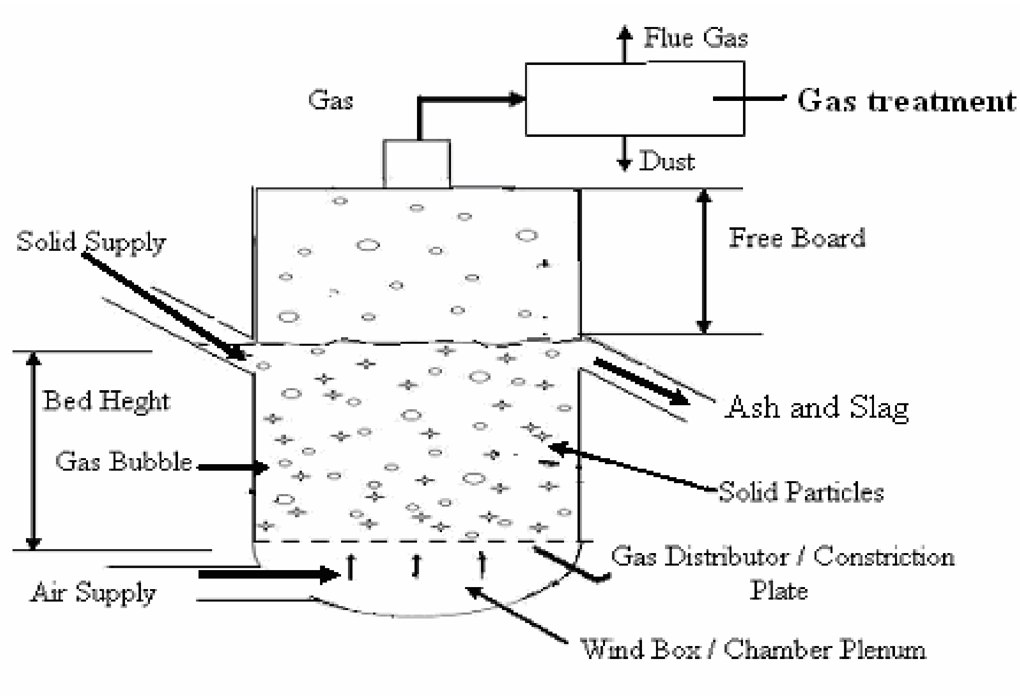


Figure 10: Non- Catalytic Fluidized Bed System

Fluidization vessel: just as for a vessel design for boiling a liquid space must be provided for vertical expansion of the solids and for disengaging splashed and entrained material. The volume above the bed is called the disengaging space. The cross sectional area is determined by the volumetric flow of gas and the allowable or required fluidizing velocity of the gas at operating conditions. In some cases the lowest permissible velocity of gas is used, and in others the greatest permissible carryover or entrainment of solids, and this related to the dimensions of the disengaging space (cross-sectional area and height).

Bed height is determined by a number of parts, either, individually or collectively such as:

- gas contact time
- length to diameter ratio required to provide staging
- space required for internal heat exchangers
- solids retention time

Generally, bed height is not less than 0.3m or more than 15m. Although the reactor is usually a vertical cylinder, there is no real limitation on shape. Many fluidized bed units are operated at elevated temperatures, for this use, refractor-lined steel is the most economical design.

The refractory serves two main purposes:-

- it insulates the metal shell from the elevated temperatures;
- it protects the metal shell from abrasion by the bed;

Depending on the specific conditions, several different refractory linings are used, when heavier refractory are required because of operating conditions insulating brick is installed next to the shell and it is insulated by firebrick to protect the insulating brick.

Free board: the freeboard or disengaging height is the distance between the top of the fluid bed and the gas- exit nozzle bubbling or turbulent-bed units. At least two actions can take place in the freeboard. The height at which entrainment becomes constant is called the transport disengaging height (TDH), and it is at this position where the cyclone inlets are most economically located.

Gas distributor: the gas distributor has considerable effect on proper operation of the fluidized bed. Basically there are two types

1. for use when the inlet gas contains solids
2. for use when the inlet gas is clean

In the latter case, the distributor is designed to prevent back flow during normal operation and during shutdown.

Except in extreme length to diameter ratios, the temperature in the fluidized bed is uniform generally the temperature at any point being in 5k (10^{o}F) rang of any other point. For all practical purposes, beds with length to diameter ratio of from 4 to 0.1 can be considered to be completely mixed continuous reaction vessels in as far as the solids are concerned.

Dust separation: it is usually necessary to recover the solids carried by the gas leaving the disengaging space or freeboard of the fluidized bed. Generally, cyclones are used to remove the major portion of these solids. As cyclones are less effective as particle size decreases, secondary collection units are frequently required, i.e. filters, electro precipitators, and scrubbers, when dry collection is not required elimination of cyclone is possible if allowance is made for heavy solids loads in the scrubber.

Instrumentation:

a. **Temperature measurement**: this usually, simple and standard temperature sensing elements are adequate for continuous use.
b. **Pressure measurement:** although successful pressure-measurement probes or taps have been fabricated by using porous materials, the most universally accepted pressure tap consists of a purged tube projecting in to the bed as nearly vertically as possible, pressure measurements taken at various heights in the bed are used to determine bed level.
c. **Flow measurement:** measurement of flow rates of clean gases present no problem. Flow measurement of dirty gases is usually avoided. The flow of solids is usually controlled.

Based on the operating condition and conversion efficiency of the equipment employed, there are two cases in the combustion of fuels, complete and incomplete combustion.

Complete combustion: Ideally, we can assume perfect combustion of fuel; in this case, the reactant will burn in oxygen, producing a limited number of products. When a hydrocarbon burns in oxygen, the reaction will only yield carbon dioxide and water. When a hydrocarbon or any fuel burns in air, the combustion products will also include nitrogen. When elements such as carbon, nitrogen, sulfur, and iron are burned, they will yield the most common oxides. Carbon will yield carbon dioxide, Nitrogen will yield nitrogen dioxide, Sulfur will yield sulfur dioxide, and Iron will yield iron (III) oxide. It should be noted that complete combustion is impossible to achieve. In reality, as actual combustion reactions come to equilibrium, a wide variety of major and minor species will be present. For example, the combustion of methane in air will yield, in addition to the major products of carbon dioxide and water, the minor products which include carbon monoxide, hydroxyl, nitrogen oxides, monatomic hydrogen, and monatomic oxygen.

Incomplete combustion: Due to different factors (operating parameter and system efficiency etc.), Incomplete combustion occurs. It occurs when there isn't enough oxygen to allow the fuel (usually a hydrocarbon) to react completely with the oxygen to produce carbon dioxide and water. The reactant will burn in oxygen, but will produce numerous products. When a hydrocarbon burns in air, the reaction will yield carbon dioxide, water, carbon monoxide, pure carbon (soot or ash) and various other compounds such as nitrogen oxides. Incomplete combustion is much more common and will produce large amounts of byproducts, and in the case of burning fuel in automobiles, these byproducts can be quite unhealthy and damaging to the environment.

3.6.1. Principles of Fluidized Bed System

Processing operations involving gas solids contacting have been markedly improved since the introduction of solids fluidization in the mid 1940s. One of the first applications was in connection with the gasification of coal, followed by the use of fluidization principles in the development fluid catalytic cracking units in the petroleum industry. Fluidized bed systems are used for several purposes, effecting reactions, heat exchange, and adsorption. Fluidization, or fluidizing, converts a bed of solid particles into an expanded suspended mass that has many properties of liquid. This mass has zero angle of response, seeks, its own level, and assumes the shape of the containing vessel. Fluidized beds are used successfully in a multitude of processes both catalytic and non-catalytic. Considerable efforts and interests are now centered in the areas of coal and waste combustion to raise steam and gasification of coal. A fluidized bed is composed of fuel coal (coal, coke, biomass, etc) and bed materials (ash, sand, and /or sorbent) contained within an atmospheric or pressurized vessel.

3.6.2. Fuel Requirement (type)

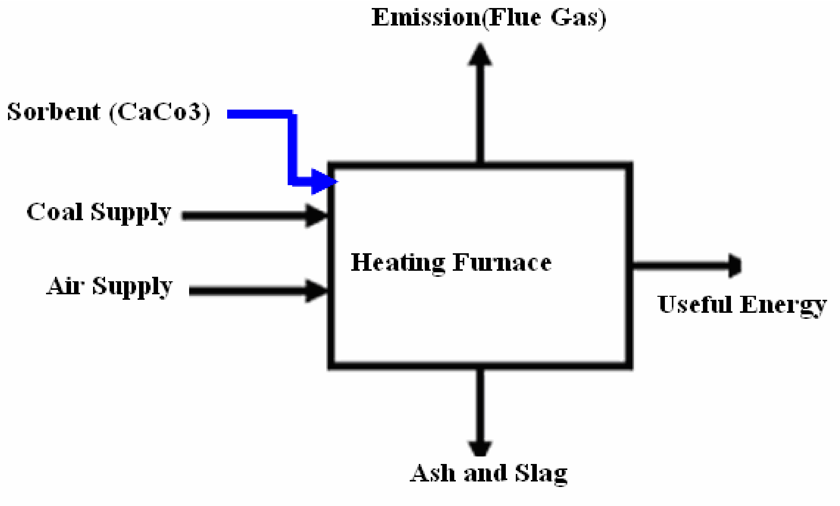
One of the popularity of fluidized bed combustion is due largely to the technology's fuel flexibility almost any combustible material from coal to municipal waste can be burned; therefore, FBC units can accommodate a variety of fuels, including both low- grade and high sulfur- fuels. The size of the feed materials depends on the reactivity of the fuel and type of feed materials larger particle sizes can be used for highly reactive fuels such as lignite and some sub bituminous coals, for this case the fuel is the Ethiopian lignite coal (Yayu coal properties shown in Table 16).

3.6.3. System Boundary for analysis

To start analysis of the system for quantitative determination of operating parameters it is better to define clearly the system boundary, a simplified representation of the furnace is shown in

Figure11. Furnace is a device where heat is transferred to a material to effect physical or chemical changes in the material (to melt zinc and lead metals in this case). The required energy is generated by the combustion of coal in side the furnace. The inputs to the system are coal lignit (Yayu coal). The Yayu coal is selected for analysis because better information is available related to the chemical and physical properties and it is the first target area for mining in the near future. The main properties of the Yayu coal are summarized in Table 16, air (oxidizer) and sorbent ($CaCO_3$) for the removal of sulfur. Emissions (flue gas), ash and slag and energy will produce as the result of combustion process. The detail analysis and description of each component will be discussed in the subsequent topics.

Figure 11: System Boundary for Analysis (simplified)



3.7.Energy Required based on the current fuel consumption

Fuel consumption of the factory (on average) is equal to 2500 litter per 40 ton of corrugated steel sheet:-

$$\left. \rho = \frac{m}{V} \right\} \qquad \textbf{[Eq 3.1]}$$

Where

m = mass (kg)

V = volume (m^3) and

ρ = density (Kg/ m^3)

Table 15 density of fuel is equal to 954.5kg/m^3 and from equation 3.1

$$\rho = \frac{m}{V} \Rightarrow m = \rho \times V = 954.5\frac{kg}{m^3} \times 2500lit \times \frac{1m^3}{1000lit} = 2386.25kg$$

Therefore, this amount of mass is required to produce 40 tons (59.66kg per ton), and, the energy that can be produced from burring of this fuel is:-

$$\left. 43.22\frac{MJ}{Kg} \times 2386.25Kg = 103133.725MJ \right\} \qquad \textbf{[Eq 3.2]}$$

3.8.Mass of Coal required to generate the calculated amount of energy

On complete combustion 103133.725MJ energy could be produced from burning of 2500litters, taking 85% of this energy is useful 8766.37MJ. The amount of coal required to generate (produce) this amount of energy if 85% the coal burn effectively is:-

$$\left. M_c = \frac{87663.7MJ}{0.85 \times 19.4\frac{MJ}{kg}} = 5317\,kg \right\} \qquad \textbf{[Eq 3.3]}$$

Table 16: Properties of Yayu Coal [3]

Property/ parameter	Value in Range	Average value	Value from burring of 5317kg of coal
Moisture content %, wt	13.58-28.4	15.23	809.94kg
Calorific value MJ per Kg	14.43-24.34	19.4	1031.50MJ
Ash content % wt	13.66-43.41	20.88	1110.19 kg
Phosphorus content % wt		0.003	0.16 kg
Total sulfur content %wt		1.59	84.54 kg
Volatile matter %		22.08	1173.99 kg
Carbon content (C_{ad}[15] % wt)		27	1435.59 kg
Hydrogen(H_{ad} % wt)		2.46	130.80 kg
Oxygen(O_{ad} % wt)		10.98	583.81 kg
Nitrogen (N_{ad} % wt)		1.02	54.23 kg

The fusion of ash is an important characteristic of coal. It greatly influences the furnace design and operating parameters, Table 17 shows the Yayu coal ash fusion temperatures.

Table 17: The Yayu Coal Ash Fusion Temperature in ^{O}c [2]

Total dissolved	1160
Total suspended	1220
Total fixed solids	1300

Ash compromises the inorganic solid residues left after the fuel is completely burned. For the Yayu coal, the average ash composition is presented in table 20 below.

---

[15] ad = air dry base

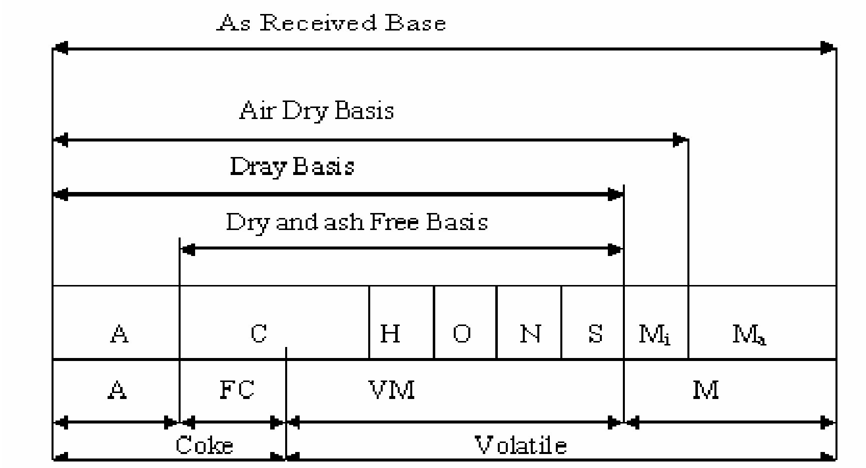
Table 18: the Average Ash Composition (% Wt) of Yayu Coal [2]

SiO_2	62.71	TiO_2	1.36
Al_2O_3	17.4	SO_3	1.23
FeO_3	6.87	K_2O	0.47
CaO	1.8	Na_2O	1.55
MgO	3.65	P_2O_5	0.21
		others	2.75

3.9.Combustion Chemistry

Coal consists of an inorganic impurity known as ash (A), moisture (M) and large number of complex organic compounds. The latter comprises five principal elements, Carbon(C), hydrogen (H), oxygen (O), sulfur(S) and Nitrogen (N), this is determined through ultimate analysis. Owing to the experimental complexity involved in ultimate analysis, another, simpler method, known as proximate analysis is some times used. In this analysis coal is considered to consist of four components, volatile matter (VM), fixed carbon (FC), ash (A) and moisture (M).

Figure 12: Composition of Coal Showing Different Basis of Preparation [19]



The ultimate and/or proximate analysis of coal may be based on different basis depending on the situation. Generally four bases are used as received, air dry, dry and ash free. A comparison of the different basis is shown in figure 12 when as received is used, the results of ultimate and proximate analysis can be written as:-

As received Basis

Ultimate:

Proximate:

$$\left.\begin{array}{l} C + H + O + N + S + A + M = 100\ \% \\ VM + FC + M + A = 100\ \% \end{array}\right\}$$ **[Eq 3.4]**

3.9.1. Basic Reactions and Quantities

When fuels burn, oxygen combines with chemical components of the fuel and releases energy in the form of heat. Since there are many components in the fuel, there are many chemical reactions associated with combustion. The basic chemical equations for complete combustion are:-

$$\left.\begin{array}{l} C + O_2 \rightarrow CO_2 \\ 2H_2 + O_2 \rightarrow 2H_2O \\ S + O_2 \rightarrow SO_2 \end{array}\right\}$$ **[Eq .3.5]**

When sufficient oxygen is not present, the carbon will be burned incompletely, with the formation of carbon monoxide as

$$2C + O_2 \rightarrow 2CO \}$$ **[Eq 3.6]**

Table 16 shows the relative mass ratio of the major elements present in the Yayu coal, and material balance is done based on this data. The base for calculation of the following quantities is the production of 40 tons product (burring of 5317kg of coal).

$$\left.\begin{array}{l} C + O_2 \rightarrow CO_2 \\ 12\,kg + 32\,kg \rightarrow 44\,kg \\ 1kg + 2.67\,kg \rightarrow 3.67\,kg \\ (C)kg + 2.67\,(C)kg \rightarrow 3.67\,(C)kg \end{array}\right\}$$ **[Eq 3.7]**

Similarly;

$$\left.\begin{array}{l} 2H_2 + O_2 \rightarrow 2H_2O \\ (1H)kg + (8H)kg \rightarrow 9(H)kg \end{array}\right\}$$ **[Eq 3.8]**

$$\left.\begin{array}{l} S + O_2 \rightarrow SO_2 \\ 32\ kg + 32 \rightarrow 64\ kg \\ (1S)\,kg + (1S)\,kg \rightarrow (2S)\,kg \end{array}\right\} \qquad \textbf{[Eq 3.9]}$$

a) Quantity of Carbon Dioxide Produced During Combustion

The total carbon dioxide produced can be calculated from Eq.3.7. Total CO_2 produced from burring of the calculated amount of coal is equal to: $3.67 \times 1435.6 = 5268.6$ kg for complete combustion.

b) Quantity of Sulfur Dioxide Produced

Sulfur contributes to the heating value of coal. It forms oxides which combine with water to form acids. These cause corrosion problems and environmental problem, Yayu coal has a sulfur content of 1.59% (Table 16). Sulfur dioxide is produced by the oxidation of sulfur in the coal, if calcium is present in the coal; it also reduced in the furnace through a reaction with the existing calcium as

$$\left. CaO + SO_2 + \frac{1}{2}O_2 = CaSO_4 \right\} \qquad \textbf{[Eq 3.10]}$$

For this analysis the sulfur in the furnace through the reaction with the calcium from the coal is assumed to be small. The amount of sulfur dioxide produced can be found from equation 3.9 that is 1Kg of sulfur can produce 2kg of sulfur dioxides; therefore, the total amount of SO_2 produced from the calculated amount of coal required to produce 40 tons is equal to $2 \times 84.54kg = 169.08$ kg.

c) Air Required for Complete Combustion

When oxygen is present in a coal, it should be considered as existing already in a combined state with part of the carbon and hydrogen, as such only the rest of the carbon and hydrogen are available for oxidation, and liberation of heat. In other words, an increase in the percentage of oxygen in fuel decreases the heat that will be liberated by combustion of fuel, and hence decreases its quality as a fuel. Oxygen required for complete combustion of 1kg of coal is:-

$$\left. W_{O_2} = 2.67C + 8H + S - O \right\} \qquad \textbf{[Eq 3.11]}$$

Where C, H, and S, represent the mass ratio of the elements of carbon, hydrogen and sulfur respectively and O is the oxygen present in the coal. Air from the atmosphere contains 23.2% oxygen by mass, therefore the air required theoretically for complete combustion is:-

$$\left.\begin{aligned}
W_{r_1} &= \frac{100\times W_{O_2}}{23.2} \Rightarrow W_{r_1} = \frac{W_{O_2}}{0.232} \\
W_{r_1} &= \frac{W_{02}}{0.232} = \frac{1}{0.232}\left(2.67C+8H-O+S\right) \\
W_{r_1} &= \frac{1}{0.232}\left(2.67C+8(H-\frac{O}{8})+S\right) \\
W_{r_1} &= 11.5C+34.5(H-\frac{O}{8})+4.3S \\
W_{r_1} &= 11.5\times(1435.6)+34.5\times\left(130.8-\frac{583.81}{8}\right)kg+4.3\times(84.54)kg = 18867.66Kg
\end{aligned}\right\}$$

[Eq 3.12]

Where W_{r_1} is theoretically required air and W_{O_2} is the mass of oxygen required for combustion, from the stoichiometric equation.

d) Sorbent Requirements

As explained previously, the most important advantage of fluidized bed combustion is the concurrent removal of sulfur dioxide that results normally from the combustion of the sulfur content of the coal. Desulphurization is accomplished by the addition of limestone directly to the bed together with the crushed coal. Limestone is a sedimentary rock composed mostly of calcium carbonate ($CaCO_3$) and sometimes some magnesium carbonate ($MgCO_3$). Limestone absorbs the sulfur dioxide with the help of some oxygen from the excess air according to the following reaction:-

$$CaCO_3 \rightarrow CaO + CO_2$$

[Eq 3.13]

The resulting lime reacts with SO_2 and oxygen to form calcium sulfate as follows

$$\left. CaO_3 + SO_2 + \frac{1}{2}O_2 \rightarrow CaSO_4 + CO_2 \right\}$$

[Eq 3.14]

and the mole balance of this equation is:-

$$\left.\begin{array}{l} CaCO_3 + SO_2 + \frac{1}{2}O_2 \rightarrow CaSO_4 + CO_2 \\ \\ 100kg + 64kg + 16kg \rightarrow 136kg + 44kg \\ \\ 1.5625(SO_2)kg + 1(SO_2)kg + 0.25(SO_2) \rightarrow 2.125(SO_2)kg + 0.6875(SO_2)kg \end{array}\right\} \quad \textbf{[Eq. 3.15]}$$

Reductions in sulfur dioxide emissions of up to 95% possible in fluidized bed combustion by this method, the calcium sulfate produced in this process is dry waste product that is either regenerated or disposed off.

Sorbent feed particle size affects the process as well as the design of unit and auxiliary equipment. Stone elutriation required Ca to S ratio, bed particle size bed bubble phenomena, and bed void-age are among the major items affected or determined by a given sorbent size and fluidization velocity.

The quantity of SO_2 that can be produced from burning of 5317 kg of coal is 4.226kg from previous results then the quantities can be calculated as follows:-

e) Quantity of $CaCO_3$ Required for the Removal of Sulfur

Mass of $CaCO_3$ $= 169.08kg \times 1.5625 = 264.2Kg$

f) Oxygen Required to Combust the Carbon in the Calcium

Mass of oxygen $= 0.25 \times 169.08kg = 42.27kg$

g) Quantity of Carbon Dioxide Produced During Sulfur Removal

Mass of carbon dioxide = $0.687kg \times 169.08 = 116.16kg$

h) Quantity of $CaSO_4$ Produced

$$2.125 \times 169.08kg = 359.3kg$$

Similarly, the mass of air required for this reaction can be calculated as:-

$$W_{r_2} = \frac{42.27}{0.232} Kg = 182.2 Kg \Big\} \qquad \textbf{[Eq 3.16]}$$

Where W_{r2} is the amount of oxygen required for desulphurization.

i) Nitrogen and Phosphorous

The quantity of phosphorous table 16 is insignificant and at the operating temperature of the fluidized bed combustion nitrogen is non combustible gas (an inert gas) and contributes nothing to the combustion process, but must be handled in the flue gas, thus both elements are neglected from the analysis.

j) Total Air Flow Required

The air required for complete combustion of the calculated quantity of coal will be: -

$$\left.\begin{aligned} W_{r_{total}} &= W_{r_1} + W_{r_2} \\ W_{r_{total}} &= 18867.7kg + 182.2kg = 19049.858\,kg \end{aligned}\right\} \qquad \text{[Eq 3.10] and [Eq 3.14]}$$

This is the minimum theoretical weight of air required for complete combustion. In actual practice, the chemically correct quantity of air will not be sufficient for complete and rapid combustion of the coal owing to imperfect mixing. Combustion reactions required more than the theoretical amount, so the actual is higher and excess air is always supplied. The ratio of the actual amount of air introduced in to the furnace combustion system (W_a) to the theoretically required (W_r) is called excess air coefficient (α), which is expressed as:-

$$\alpha = \frac{W_a}{W_r} \Big\} \qquad \textbf{[Eq 3.17]}$$

And the percentage of excess air supplied can be calculated as:-

$$\frac{W_a - W_r}{W_r} \times 100 \Big\} \qquad \textbf{[Eq 3.18]}$$

The value of excess air coefficient (α), depends on the kind of fuel fired and the furnace design and ranges from 1.03 for gaseous fuel to 1.50 for solid fuels, taking the value of 1.5 for the case of solid coal (α =1.5)[16].

$$W_a = W_{r_{total}} \times \alpha_{=1.5} = 19049.86\,kg \times 1.5 = 28574.787\,kg \} \quad \textbf{[Eq 3.19]}$$

And the quantity of air required per hour can be calculated as:-

$$W_a = \frac{28574.8\,kg}{24\,hrs} = 1190.6 \frac{kg}{hrs} \Big\} \quad \textbf{[Eq 3.20]}$$

It should be remembered that the excess air supplied will not take part in the combustion process, but only helps for perfect mixing and combustion of the coal supplied. However, when excess air is added, some of the heat generated by the combustion process is lost to the excess air. This is preferable to the undesirable product of incomplete composition.

k) Total Carbon Dioxide Produced from the System

Carbon dioxide is produced from both combustion of carbon in the coal and calcinations of sorbents(calcium carbonate), therefore, total mass of carbon dioxide that will produced from both sources is $5268.6153\,kg + 116.2\,kg = 5384.77\,kg \}$

This expression neglects the presence of magnesium in limestone and any CaO in the coal.

l) Flue Gas Moisture Content

Coal may have moisture content in two forms, inherent and surface. The surface moisture (Ma), which is gathered by the coal during storage etc., can be removed by air drying. However, the inherent moisture (M_i) which is trapped in coal during its geological formation is not released except during combustion. In any case, the two forms of moisture and that formed through combustion of hydrogen in the coal contribute to the moisture in flue gas. The weight of water vapor, equation 3.8 is nine times the weight of the hydrogen appearing in the reaction, therefore, the amount of water that can be produced from oxidation of the existing hydrogen is $9 \times 130.8\,kg = 1177.2\,kg \}$.

The moisture content in dry air (X_m Kg/kg) depends on the relative humidity and barometric pressure. A typical value of X_m is 0.013, thus;

Total moisture content = (Moisture in the coal) + (Moisture in combustion air) + (Combustion of hydrogen in coal) that is $809.94\,kg + 1177.2\,kg + 28574.78\,kg \times 0.013 = 2358.6\,kg \}$ **[Eq 3.21]**

3.9.2. Coal and Air flow Rates

Based on the production rate of the Case Factory energy demand and the calculated amount of coal required to produce this energy demand, it is possible to calculate the mass flow rate of coal and air for combustion.

3.9.3. Quantity of Ash and Slag

Ash is non- combustible matter in coal. Bottom ash and slag are the coarse, granular, incombustible by-products that are collected from the bottom of furnaces that burns coal. The type of by-product (i.e., bottom ash or slag) produced depends on the type of furnace used to burn the coal. The high combustion efficiency of a fluid bed results in a reduced amount of inorganic material as fine ash.

Based on the coal consumption ash and slag discharge can be calculated as [3]:-

$$G = B_m (A + q) + B_s \} \qquad \text{[Eq 3.22]}$$

Where:-

G = discharge amount of ash and slag (kg)

B_m = coal consumption (kg)

A = the ash content of the coal (%)

q = mechanically imperfect combustion loss of coal, generally (4.5%)

B_s = consumption of limestone (kg)

Therefore;

$$G = 5317kg(\frac{20.88 + 4.5}{100}) + 264.2kg = 1613.64kg$$

The ratio of ash to slag is 6: 4, so the ash discharge amount is 1613.64x 0.60 = 968.2kg, and the amount of slag is 1613.64x 0.40 = 645.5Kg.

Fly Ash Removal

Fly ash can be removed by installing fly ash traps, recycling for re-burning

Other options include;-

- Building a stack of adequate height from the beginning
- Install one of the several designs of fly ash catchers commercially available

- Pass all the stack gases through an air washer some where between the boiler outlet and the stack

Firing of fluidized bed combustion system

The firing (ignition) is achieved by direct oil injection in to the lower furnace section, in which a zone of increased solids connection is formed by dividing the fluidized air into primary and secondary air.

3.9.4. Stages of Fluidization and Pressure Drops

Consider the sequence of events as gas flows through a bed of solids initially at rest, as the flow rates increases the bed expands and some particles begin to move about in a restricted region (expanded bed). A point is reached upon further increase in gas flow rate at which the solids all just become suspended. This region is called incipient or minimum fluidization, and at this point weight gradient of the bed is equal to the pressure gradient due to drag on the particles [13].

As the superficial velocity (U_c) approaches the minimum fluidizing (or critical) velocity (V_{mf}), the bed starts to expand and when the particles are no longer in physical contact with one another the bed is fluidized. The pressure gradient then becomes lower because of the increased voidage and, consequently, the weight of particles per unit height of bed is smaller [7].

Theoretical values of the minimum fluidizing velocity is calculated by equating the pressure drop through the bed to the weight of particles per unit area, and the porosity set at the maximum value that can be attached in the fixed bed. In a fluidized bed, the total frictional force on the particles must equal the effective weight of the bed. The relation between fluid velocity (U_c), pressure drop ($-\Delta P$) and voidage (e) is given, for a fixed bed of spherical particles of diameter (d) [7].

$$U_c = 0.0055\frac{\left(e^3\right)}{(1-e)^2}\times\left(-\frac{\Delta P d^2}{H\mu}\right)\Rightarrow U_c = 0.0055\left(\frac{e^3}{1-e}\right)\times\left(\frac{d^2(\rho_s-\rho_a)g}{\mu}\right) \qquad \textbf{[Eq 3.23]}$$

Where, g is acceleration due to gravity, H is thickness of the bed; ρ_s and ρ_a are the densities of solid particle and air (gas) respectively. This relation applies from the initial expansion of the bed until transport of solids takes place.

For a fluidized bed the buoyant weight of the particles is counterbalanced by the frictional drag force. As the upward velocity of the flow of fluid through a packed bed of uniform spheres is increased, the point of incipient fluidization is reached when the particles are just supported in the fluid. The corresponding value of the minimum fluidizing velocity (U_{mf}) is then obtained by substituting e_{mf} (porosity at fluidization). The value of e_{mf} will be a function of the shape, size distribution and surface properties of the particles,

$$\left(U_{mf}\right) = 0.0055\left(\frac{e_{mf}^{\;3}}{1-e_{mf}}\right)\left(\frac{d^{2}(\rho_s-\rho_a)g}{\mu}\right) \qquad \textbf{[Eq 3.24]}$$

Substituting a typical value of 0.4 for e_{mf} gives

$$\left(U_{mf}\right)_{e_{mf}=0.4} = 0.00059\left(\frac{d^{2}(\rho_s-\rho_a)g}{\mu}\right) \qquad \textbf{[Eq 3.25]}$$

and the general equation that relates pressure gradient and fluid velocity for all flow regimes at the point of incipient fluidization is:

$$-\frac{\Delta \mathrm{P}}{H} = 150\left(\frac{(1-e)^{2}}{e^{3}}\right)\times\left(\frac{U_c\mu}{d^{2}}\right)+1.75\left(\frac{(1-e)}{e^{3}}\right)\times\left(\frac{U_c^{\;2}\rho_a}{d}\right) \qquad \textbf{[Eq 3.26]}$$

Where

$-\Delta$P	pressure drop across bed due to the presence of solids;
H	height of the bed;
e	porosity;
d	diameter of the sphere with the same volume surface area ratio as the particles; and
μ	viscosity of fluid(air in this case)

Substituting e = e_{mf} at the incipient fluidization point, and U_c by U_{mf}

$$\frac{\left(1-e_{mf}\right)\left(\rho_s-\rho_a\right)Hg}{H} = 150\left(\frac{\left(1-e_{mf}\right)^{2}}{e_{mf}^{\;3}}\right)\left(\frac{U_{mf}\mu}{d^{2}}\right)+1.75\left(\frac{1-e_{mf}}{e_{mf}^{\;3}}\right)\times\left(\frac{\rho_a U_{mf}^{\;2}}{d}\right) \qquad \textbf{[Eq 3.27]}$$

Multiplying both sides by

$$\frac{\rho_a d^3}{(1-e_{mf})\mu^2}$$ **[Eq 3.28]**

$$\left.\frac{\rho_a(\rho_s-\rho_a)gd^3}{\mu^2}=150\left(\frac{1-e_{mf}}{e_{mf}^{\;3}}\right)\left(\frac{U_{mf}d\rho_a}{\mu}\right)+\left(\frac{1.75}{e_{mf}^{\;3}}\right)\left(\frac{U_{mf}d\rho_a}{\mu}\right)^2\right\}$$ **[Eq 3.29]**

by definition

$$\left.\frac{d^3\rho_a(\rho_s-\rho_a)g}{\mu^2}=Ga\right\}$$ **[Eq 3.30]**

is the ‘Galileo number’ and

$$\frac{U_{mf}d\rho_a}{\mu}=\mathrm{Re}_{mf}$$ **[Eq 3.31]**

is particles Reynolds number at the minimum fluidizing velocity, therefore;

$$\left.Ga=150\left(\frac{1-e_{mf}}{e_{mf}^{\;3}}\right)\mathrm{Re}_{mf}+\left(\frac{1.75}{e_{mf}^{\;3}}\right)\mathrm{Re}^2{}_{mf}\right\}$$ **[Eq 3.32]**

for $e_{mf}=0.4$

$$\left.Ga=1406.25\,\mathrm{Re}_{mf}+27.3\,\mathrm{Re}^2{}_{mf}\;\Rightarrow\;\mathrm{Re}^2{}_{mf}+51.4\,\mathrm{Re}_{mf}-0.0366Ga=0\right\}$$ **[Eq 3.33]**

by definition :

$$\left.U_{mf}=\frac{\mu}{d}\mathrm{Re}_{mf}\right\}$$ **[Eq 3.34]**

The relationship between voidage at the minimum fluidizing velocity, e_{mf} and particle shape factor Φ_s, which is defined as the ratio of the diameter of the sphere of the same specific as the particle (d) to the diameter of the sphere with the same volume as the particle d_p [7].

Thus: $\Phi_s = \frac{d}{d_p}$ where: $d = \frac{6V_p}{A_p}$ and $d_p = \left(\frac{6V_p}{\Pi}\right)^{\frac{1}{3}}$

The minimum fluidizing velocity is a function of both e_{mf} and *$\Phi_{s,}$* neither of which is easily measured (or estimated). The correlation between e_{mf} and *Φ_s* is given as:

$$\left.\left(\frac{1-e_{mf}}{e_{mf}{}^3}\right)\frac{1}{\Phi^2{}_s} = 11\right\} \qquad \textbf{[Eq 3.35]}$$

and

$$\left.\left(\frac{1}{e_{mf}{}^3 \times \Phi_s}\right) = 14\right\} \qquad \textbf{[Eq 3.36]}$$

on substitution of $\frac{\Phi_s}{d_p}$ for d in equation 3.29

$$\left.(1-e_{mf})(\rho_s-\rho_a)g = 150\left(\frac{(1-e_{mf})^2}{e_{mf}{}^3}\right)\frac{1}{\Phi^2{}_s}\left(\frac{\mu U_{mf}}{d^2{}_p}\right) + 1.75\left(\frac{1-e_{mf}}{e^3{}_{mf}}\right)\left(\frac{\rho_a U_{mf}{}^2}{\Phi_s d_p}\right)\right\} \qquad \textbf{[Eq 3.37]}$$

Thus:

$$\left.\left[\frac{\rho_a(\rho_s-\rho_a)gd_p{}^3}{\mu^2}\right] = 150\left[\left(\frac{(1-e_{mf})}{e_{mf}{}^3}\right)\frac{1}{\Phi^2{}_s}\left(\frac{\rho_a d_p U_{mf}}{\mu}\right)\right] + 1.75\left[\left(\frac{1}{e^3{}_{mf}\Phi_s}\right)\left(\frac{\rho_a{}^2 d_p{}^2 U_{mf}{}^2}{\mu^2}\right)\right]\right\} \qquad \textbf{[Eq 3.38]}$$

On substitution of the values from equations 3.37 and 3.38:

$$\left.G_{ap} = (150\times 11)\mathrm{Re}_{mfp} + (1.75\times 14)\mathrm{Re}^2{}_{mfp}\right\} \qquad \textbf{[Eq 3.39]}$$

Where Ga_p and Re_{mf} are the Galilo number and the particle Reynolds number at the point of incipient fluidization, in both cases with the linear dimension of the particles expressed as d_p.

To find the minimum fluidization (critical) velocity the following values are taken

- density of coal 694kg/m^3
- density of calcium carbonate 2711kg/m^3
- Viscosity of air @20^{0}C=1.81x10^{-5}pa-s(N-S/m^2)
- Density of air @20^{0}C=1.2kg/m^3

Generally for fluidized coal combustion particle size range is from 6mm to 25mm, for the particular lignite coal 25mm is recommended since it can bur easily.

The bed contains the coal particle and calcium carbonate (sorbent), weight of the bed will be the sum of coal and calcium carbonate.

$$\left. Ga = \frac{d^3\rho_a(\rho_s-\rho_a)g}{\mu^2} = \frac{(25\times10^{-3}m)^3\left(1.2\frac{kg}{m^3}\right)\times((694+2711)-1.2)\frac{kg}{m^3}\times\left(9.81\frac{m}{s^2}\right)}{(1.81\times10^{-5})^2\frac{kg}{ms}} = 1.91\times10^9 \right\} \quad \textbf{[Eq 3.40]}$$

$$\left. (R'e_{mf})_{e_{mf}=0.4} = 25.7\left[\sqrt{(1+(5.53\times10^{-5})Ga)}-1\right] \Rightarrow 25.7\left[\sqrt{(1+(5.53\times10^{-5}\times1.91\times10^{9}))}-1\right] = 8.327\times10^3 \right\}$$

[Eq 3.41

$$\left. \text{and} \quad U_{mf} = \frac{\mu}{d\rho_a}\text{Re}_{mf} = \frac{1.81\times10^{-5}\frac{kg}{ms}\times8.327\times10^3}{25\times10^{-3}\times1.2\frac{kg}{m^3}} = 5.024\frac{m}{s} \right\} \quad \textbf{[Eq 3.42]}$$

The total pressure drop △P$\left(\frac{N}{m^2}\right)or(Pa)$, in a fluidized bed is composed of three components [16]:

$$\left. \Delta P = \Delta P_w + \Delta P_s + \Delta P_f \right\} \quad \textbf{[Eq 3.43]}$$

Where:

△P_w = pressure drop due to friction at the wall

△P_s = pressure drop due to static weight of solid in bed

△P_f = pressure drop due to static weight (hydrostatic head) of fluid in bed)

At high flow rates, the drag force on the particles will act to lift them off the surface. The pressure drop across the bed will increase with increasing flow rate and at some point will exactly equal the weight of the bed. As the gas flow is increased beyond the minimum fluidization velocity, voids that are essentially free of solid particles begin to form and move upward these voids act much like bubbles in a liquid system. The voids grow as they rise in the bed due to pressure reduction.

Fluidized beds usually have large wall diameters, so ΔP_w is relatively small. The air in a fluidized combustor varies in a complex manner from air to hot gaseous combustion products; their average density is much smaller than that of the solids, and $\triangle P_f$ therefore, is also relatively small, thus

$$\left.\Delta P = \Delta P_s = H(1-\alpha)\frac{\rho_s g}{g_c}\right\} \quad \textbf{[Eq 3.44]}$$

Where:

g_c = conversion factor $= 1\frac{kg \times m}{N \times S^2}$

H = height of bed in fluidized bed (m)

α = average porosity or void fraction of bed in fluidized state

= fraction not occupied by solids, dimensionless.

The value of α is obtained from $\left(\frac{1-\alpha}{1-\alpha_0} = \frac{H_0}{H}\right)$ **[Eq 3.45]**

Where;

Ho = height of the bed in the collapsed state, i.e. when all solids are, randomly packed at bottom.

α_O = porosity in the collapse state, the value of α_O of a bed of spheres of equal diameter, randomly packed is very nearly equal to 0.40, but lower for sphere of different diameters

To calculate the volume of the coal required for one hour

$$Density(\rho) = \frac{Mass(m)}{Volume(V)}$$

Where;

$$\left.\begin{aligned} M_c &= 222 \ Kg \\ \rho &= 694 \ \frac{kg}{m^3} \end{aligned}\right\} \quad \textbf{[Eq 3.46]}$$

Therefore;

$$\left.V = \frac{222kg}{694\frac{kg}{m^3}} = 0.32m^3\right\} \quad \textbf{[Eq 3.47]}$$

and the volume is equal to the base area times height , from (Annex (A))

$A = 2930mm \times 2250mm = 6.5925m^2$

$$\left.\begin{aligned} &H_0 = \frac{V}{A} = \frac{0.32m^3}{6.5925m^2} = 0.0485m = 48.5mm \\ &H_1 = 325mm \\ &\mathrm{H_2 = H_1 + 910mm = 325mm + 910mm = 1235mm} \end{aligned}\right\}$$

[Eq 3.48]

It is necessary to calculate the porosity at the calculated heights ($H_1$and H_2) from Equations 3.44 and 3.45.

<u>Consider two cases</u>

<u>Case one:</u> When the bed fluidization height is H_1

$$\frac{1-\alpha_1}{1-\alpha_0} = \frac{H_0}{H_1} \Rightarrow \alpha_1 = 1 - \frac{H_0}{H_1}\left(1-\alpha_{0=0.4}\right)$$

$$\alpha_1 = 1 - \frac{0.0484m}{0.325m}(1-0.4) = 0.91064615$$

<u>Case two:</u> When the bed fluidization height is H_2

$$\frac{1-\alpha_2}{1-\alpha_0} = \frac{H_0}{H_2} \Rightarrow \alpha_1 = 1 - \frac{H_0}{H_2}\left(1-\alpha_{0=0.4}\right)$$

$$\alpha_2 = 1 - \frac{0.0485m}{1.235m}(1-0.4) = 0.97648583$$

Taking the average value of α_1 and $\alpha_{2:}$

$$\left.\alpha = \frac{\alpha_1 + \alpha_2}{2} = \frac{0.97648583 + 0.910646151}{2} = 0.944\right\}$$

[Eq 3.49]

The pressure drop can be calculated based on the average value of porosity Eq.3.46, since the objective is to heat the zinc pot to the height of H_2, this height is taken as the effective height in calculating the pressure drop in the bed.

Therefore: $$\left.\Delta \mathrm{P} = 1.235m \times (1-0.944) \times \frac{(694+2711)\frac{kg}{m^3} \times 9.81\frac{m}{s^2}}{1\frac{kg \times m}{N \times S^2}} = 2310.15\,pa\right\}$$

[Eq. 3.50]

3.10. Material and Energy Balances

3.10.1. Material Balance

The basic calculations associated with chemical reactions of combustion are described in previous sections of this thesis. The calculated quantity of the components of the system is summarized in Table 19.

Table 19: Calculated Coal Combustion Products

Components	Quantity (kg)
Input	
Air	28574.8
Coal	5317
$CaCO_3$	264.2
Out Puts	
Slag	645.5
CO_2	5384.8
Water in flue gas	2358.6
Ash	968.2
$CaSO_4$	359.3
Volatile matter	1174

Considerations and constants

- Average operating temperature 470°C;
- Ambient air temperature 25 °C;
- heating value of coal 19.4MJ per kg ;

3.10.2. Energy Balances

3.10.2.1. Heat Gain by Lead and Zinc in the Zinc Pot (Required Energy)

The objective of the heating furnace is to melt the zinc and lead in the zinc pot to coat the steel sheet products. Melting is a process of changing the phases of solid (Zinc and Lead) to a liquid phase. It involves heating the solid up to melting temperature and then supplying enough energy to change the phases from solid to a liquid (heat of fusion). Finally, both liquid metals will be heated up to the operating temperatures of the process (470^{o}C), therefore, the specific heat energy required by Zinc and Lead is given by [1].

$$q_m = C_p\left[\left(T_m - T_o\right) + \left(T_f - T_o\right)\right] + Heat_{fusion} \qquad \textbf{[Eq 3.51]}$$

And the total energy (heat) absorbed by the system can be found by multiplying the specific heat energy by the total mass i.e.

$$Q = \left(q_m\right) \times Mass \qquad \textbf{[Eq 3.52]}$$

Where:

Cp	specific heat of the solid
T_m	melting temperature of the solid
T_o	initial temperature of the solid
$Heat_{fusion}$	Heat of fusion of the solid (latent heat)
T_f	final (operating) temperature
q_m	specific heat energy
Q	total heat energy

Table 20: Heat Gain by the system (Required energy)

Metal [16]	Required mass(kg)	Heat capacity (KJ per Kg x K)	Temperature Change		Heat of fusion(KJ per Kg)	Energy(MJ) Column[(3x(4+5)+6)x2]
			T_m-T_o	T_f-T_m		
Zinc(Zn)[17]	3449.5	0.46	395	50	23	785.5
Lead(Pb)[18]	24000	0.431	302	143	112	7291.08
Total						8076.5

---

[16] From the total volume of Zinc pot the mass of Zinc is 2.5ton (10%) and Mass of Lead is 24 ton (90%)

[17] Molecular weight of Zinc(Zn) 65.39,Density 7.11g.cm^{-3}@20 ^{O}C, Melting point 420^{O}C and Boiling point 907 ^{O}C

[18] Molecular weight of Lead(Pb) 207.20 Density 11.34 g.cm^{-3}@20 ^{O}C, Melting point 327 ^{O}C and Boiling point 1715 ^{O}C

Table 20 shows the calculated values of the required energy. The heat absorbed by Zinc and Lead is considered as required energy of the system and will come from the heat released by the combustion of coal. For variety of reasons the heat released can't fully utilized, heat loss is unavoidable. The heat balance in this section is therefore necessary to show how much heat is effectively used and how much of it is lost. During the production of this required energy, the energy losses from the system can be grouped as surface loss (radiation, convection), flue gas loss, ash loss and slag loss.

3.10.3. Heat Transfer Rate

Heat transfer is concerned with the physical processes underlying the transport of thermal energy due to a temperature difference (gradient). Rate of heat transfer is equal to the product of a driving force and a thermal conductance; these factors vary for each mode (conduction, convection and radiation) [14].

Heat will transfer from the furnace to the zinc and lead metals inside the pot through conduction mode of transmission. The sequence of transfer in the composite layers will be from the furnace to the zinc through the pot and lead. Heat flowing across an area is equal to a proportionality constant, the thermal conductivity (k), times the temperature gradient at the point of interest that is:-

$$q = -kA\frac{dT}{dl} \qquad \textbf{[Eq 3.53]}$$

Where:

Q	is the directional heat flow rate (watts)
A	area normal to the direction of heat flow (m^2)
$\frac{dT}{dl}$	Transfer gradient in the direction of heat flow ($^oK/m$)
k	thermal conductivity $\left(\frac{watt}{meter \times kelvin}\right)$

The negative sign is necessary to account for the fact that heat flow by conduction occurs in the direction of a decreasing temperature gradient. Denoting $k_{s,}$ k_l and k_z as the thermal conductivity of steel (zinc pot), lead and zinc respectively; and $T_{b,}$ $T_{s,}$ T_l and T_o as the temperatures of bed, pot, lead and operating the heat transfer rate for each part of this process can be written as:-

$$q_{bed \to lead} = -k_s A_s \frac{dT}{dL}$$

$$q_{lead \to zinc} = -k_l A_l \frac{dT}{dl}$$ **[Eq 3.54]**

For steady- state case, the expression will take the same form; the difference being is the limits of integration $q_{bed \to lead} \int_0^l dx = -k_s A \int_{T_b}^{T_l} dT \Rightarrow q_{bed \to lead} = \frac{k_s A_s}{L_s}(T_s - T_l)$

Similar approach applies to all the other layers. For steady state conduction through a plane wall, the temperature profile is linear. Steady state also requires that all of the heat flow will be same, thus;

$$q = \frac{k_s A_s}{L_s}(T_s - T_l) = \frac{k_l A}{l_l}(T_l - T_o)$$ **[Eq 3.55]**

Each temperature difference can be written in terms of (q) as:

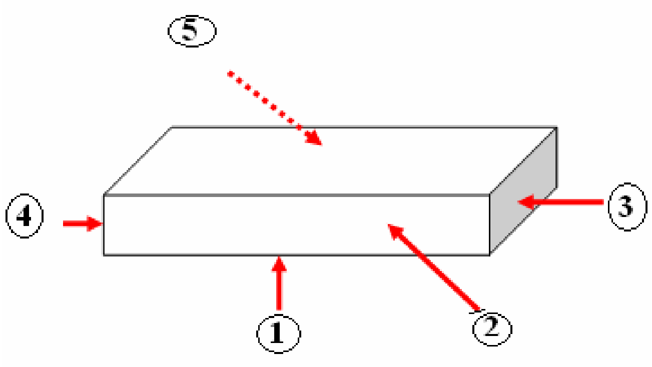
$$T_l - T_o = q\left(\frac{L_l}{k_l A_l}\right)$$

$$T_s - T_l = q\left(\frac{L_s}{k_s A_s}\right)$$ **[Eq 3.56]**

Adding and rearranging:-

$$T_s - T_o = q\left(\frac{Ls}{ksA_s} + \frac{L_l}{k_l A_l} + \frac{L_z}{k_z A_z}\right) \Rightarrow q = \frac{T_s - T_o}{\frac{L_s}{k_s A_s} + \frac{L_l}{k_l A_l} + \frac{L_z}{k_z A_z}}$$ **[Eq 3.57]**

Where the subscript s, l and z stand for the steel (pot), lead and zinc layers respectively. Heat will flow from the five sides of the zinc pot as indicated in the following figure[19].



Considering the heat flow from each face, the results are shown in Table 21.

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[19] 1,2,3 and 4 are Zinc Pot faces

Table 21: Heat Transfer Rates to Zinc and Lead Metals

Faces	Temperature in degree Kelvin(°K)		Thicknes(m)			Thermal conductivity $\left(\frac{watt}{meter \times Kelvin}\right)$			Area normal to direction of heat flow(m^2)			Heat transfer rate(watt)
	T_b	T_o	L_l	L_s	L_z	k_s	k_l	K_z	A_s	A_l	A_z	
												To Zinc Metal
1	1098	743	0.81	0.038	0.09	39.6	16.5	54	3.65	3.65	3.65	25888
2 & 5			0.801	0.038	0.801				0.205	1.85	0.205	151678.4
3&4			1.14	0.038	1.14				0.144	1.298	0.144	106544.8
											Total	**284111.3**
												To Lead Metal
1	1098	743	0.81	0.038	0.09	39.6	16.5	54	3.65	3.65	3.65	1350308
2 & 5			0.801	0.038	0.801				1.85	1.85	0.205	1368805.3
3&4			1.14	0.038	1.14				1.298	1.298	0.144	960383.4
											Total	**3679496.5**

The heat transfer from the furnace to the zinc metal is 284111.26 watt (joules per second) and to the lead is 3679496.53 watt (joules per second).

3.10.4. <u>Heat Loss Through Ash and Slag</u>

When coal is burned, ash and slag leave the furnace at a rather higher temperature (about 600-800^{O}C), this results in sensible heat loss. For this analysis the average value 700^{o}C is taken and 25^{o}C initial temperature is assumed. From the ash and slag analysis one kg of coal results on 0.30347kg of ash and slag, the energy loss in terms the major components is calculated and shown in Table 23.

Table 22: Heat Loss through the Sensible Heat of Ash and Slag

Component	Weight (%)	Mass $\frac{Kg}{kg\ Coal}$	Molecular weight	$\frac{kg(mole)}{(kg)coal}$	Specific heat $\frac{(Cal)}{Deg \times mole}$	Energy in calorie(cal) Column $[5 \times 6] \times [\Delta T = 670]$
SiO_2	62.71	0.190	60	0.0032	10.75	22.808
Al_2O_3	17.4	0.053	102	0.0005	18.87	6.569
Fe_2O_3	6.87	0.021	104	0.0002	24.73	3.346
CaO	1.80	0.005	56	$9x10^{-5}$	10.23	0.612
MgO	3.65	0.011	40	0.0003	8.87	1.634
TiO_2	1.36	0.004	80	$5\ x10^{-5}$	13.59	0.455
K_2O	0.47	0.001	94	$1x10^{-5}$	45.51	0.324
Na_2O	1.55	0.005	62	$8x10^{-5}$	48.37	2.614
P_2O_5	0.21	0.001	142	$7x10^{-6}$	48.26	0.228
Others [20]	2.75	0.008	-	6x10-5	-	0.761
$CaSO_4$(from sorbent)		0.0343	136	0.0003	23.30	3.937
Total						**43.28843** **(0.181KJ)**

3.10.5. Surface Heat Losses

Consider the heat losses from the walls of the furnace, which are associated with convection and radiation, useful formulas for these heat losses are given by [1]. Thermal radiation is that part of the electromagnetic emission of a substance that is characterized by heat transfer, and in convective heat transfer situations the energy exchange occurs between a surface and adjacent fluid (air in this case)[14].

Radiation heat losses (R_l)

$$R_l = A \times 0.1714 \times 10^{-8} \left(T_S{}^4 - T_R{}^4 \right) \qquad \text{[Eq 3.58]}$$

---

[20] The energy loss value of others component is calculated based on the mass ratio.

Convective heat losses (C_l)

$$C_l = A \times 0.18 \times (T_S - T_R)^{\frac{4}{3}} \qquad \textbf{[Eq 3.59]}$$

Where:

A is surface area in (ft^2);

C_l Convective heat loss

R_l radiative Heat loss

$0.1714X10^{-8}$ is Stefan-Boltzman constant in $\left(\frac{Btu}{hour \times ft^2 \times \left({}^0R^4\right)}\right)$ and ${}^0R = \left(\frac{9}{5}\left({}^0K\right)\right)$ and T_S and T_R are surface and room temperatures (${}^oR$), respectively

$$T_S = 40^0\,C = 313^0\,K$$

$$T_R = 25^0\,C = 298^0\,K$$

The exposed surface (A_E) can be calculated from the furnace area (Annex: A)

$$\left. A_E = 2.25m \times 1.235m \times 2 + 2.93m \times 1.235m \times 2 = 12.7946m^2 \right\} \qquad \textbf{[Eq. 3.60]}$$

Radiative heat losses (R_L)

$$\left. R_L = \left(0.1714 \times 10^{-8}\right) \times \left[\left(313 \times \frac{9}{5}\right)^4 - \left(298 \times \frac{9}{5}\right)^4\right] = 314.6 \frac{Btu}{ft^2 \times hr} \right\} \qquad \textbf{[Eq. 3.61]}$$

Convective heat losses (C_L)

$$\left. C_L = (0.18) \times \left[\left(313 \times \frac{9}{5}\right) - \left(298 \times \frac{9}{5}\right)\right]^{\frac{4}{3}} = (0.18) \times (27)^{\frac{4}{3}} = 14.58 \frac{Btu}{ft^2 \times hr} \right\} \qquad \textbf{[Eq 3.62]}$$

The total exposed surface are is 137.7 ft^2, therefore the total surface loss is:

$$\left. A_E \times (R_L + C_L) = 137.7 ft^2 \left[\left(14.58 \frac{But}{ft^2 \times hr}\right) + \left(314.6 \frac{Btu}{ft^2 \times hr}\right)\right] = 62488 \frac{Btu}{hr} = 453281 \frac{KJ}{hr} \right\} \qquad \textbf{[Eq 3.63]}$$

3.10.6. Heat Losses Due to Flue Gas

Heat losses of flue gas depend on the amount of combustion air provided and can be computed from the flue gas composition and from the stack gas temperature. The heat loss in the flue gas (combustion products) is calculated based on the properties of Yayu coal shown in table 16. The flue gas from the combustion of coal will consist of CO_2, SO_2, N_2 and water vapour therefore; the total weight of the flue gas is the weight of gaseous products of complete combustion of the coal burning with required amount of air. Finally, air is approximately 76.85%N_2 and 23.15%O_2 by weight; therefore, the excess air $\left(W_a - W_{r_{total}} = 9525kg\right)$, needed for complete combustion translates in to 2205kg of O_2 and the nitrogen from the total air for combustion is 21959.7kg. Combustion raises the temperature of all combustion products sent up the flue gas. The flue gas Components and the respective heat (sensible heat) losses is calculated and summarized in Table 23.

Table 23: Heat Loss through Flue Gas (Sensible[21] Heat Loss)

Component of flue gas	Component (Kg)	Component weight (%)	Kg of component per kg of flue gas	Molecular weight	$\frac{kg(mole)}{(kg)fluegas}$	Specific heat $\frac{(Cal)}{Deg \times mole}$	Change in temperature[22]	Energy in calorie(cal) Column (7x8x9)
CO_2	5384.8	45.31	0.453	44	0.003827	8.955	125	4.28
[23]H_2O	0.013x2858.6 + 1177.2+809.94	17.03	0.170	18	0.004098	8.786	125	4.50
N_2	54.23 from coal + 21959.7 from air	18.96	0.190	28	0.024585	6.798	125	20.89
O_2	2205.02	18.55	0.186	32	0.002155	6.233	125	1.68
SO_2 (10%)	16.908	0.14	0.001	64	0.000008	9.206	125	0.01
Total	31979.24							**31.36** **(0.131KJ)**

The flue gas heat loss is 0.131KJ per kg of flue gas and the total amount of flue gas that will produced is 799.42kg , therefore the total heat loss is 10.472KJ.

---

[21] Sensible heat: is the quantity of heat when added to or removed from a substance results in change of temperature.

[22] Change in temperature is 423-298 = 125(°K).

[23] At standard air 0.013H_2O kg/kg of dry air exists.

The total heat loss by the flue gas includes the sensible heat and the latent heat[25] necessary to convert water in to water vapour. The exhaust flue gas temperature of combustion is generally in the range of 120-180^{O}C, hence, the temperature of combustion is rarely cooled to the initial temperature of steam. The water vapor in the flue gas does not condense, and the latent heat of vaporization is not recovered. There are three sources of this water; water created as a combustion product (due to reaction of oxygen and hydrogen gases), moisture in the coal (fuel), and moisture in combustion air those total 2358.6kg per 5317kg of coal Table 23), since one kg coal becomes 6.01456kg of wet flue gas, the amount of water in 31979.24kg of flue gas is 0.07376kg. The latent heat of water is 2257KJ per kg, a total latent heat of:-

$$\left. 0.07376kg \times 2257\frac{kJ}{kg} = 166.53\frac{KJ}{(Kg)fluegas} \right\} \qquad \textbf{[Eq 3.64]}$$

Together with the sensible heat losses from Table 23 , the total heat loss per kg of flue gas is

$$0.013Kj + 166.53KJ = 166.66\frac{Kj}{kg}.$$

To determine the energy needed to produce 1kg of flue gas one kg of coal combines with the combustion air to create 6.01456Kg of wet flue gas or 714.314Kg of dry gas, therefore, the heat lost is equal to:

$$\left. \frac{19.4MJ}{6.01456kg} = 3.23\frac{MJ}{(kg)fluegas} \right\} \qquad \textbf{[Eq 3.65]}$$

and loss of 166.661KJ per kg of flue gas represents as a loss of efficiency

$$\left. \frac{166.661\,KJ}{3.23\,MJ} \times 100 = 5.16\,\% \right\} \qquad \textbf{[Eq 3.66]}$$

3.10.7. Heat Recovery Options

The heat losses through flue gas, ash and slag can be recovered to be reused as a source of energy for the production system. There are three potential recovery options:-

1. to preheat the air for combustion;
2. to generate steam to be used for washing of the product in the production line;
3. to preheat the coal or zinc and lead metal ingots;

---

[25] Latent heat is quantity of heat that changes the physical state of a substance with out changing its temperature

But, these all options need detailed study and are left for further studies.

3.10.8. Effects of Incomplete Combustion

In the above, flue gas calculations are based on the assumption of complete combustion of coal producing only the calculated components , however, combustions never come to perfect (100% complete), the presence of carbon monoxide in the flue gas is the measure of incomplete combustion, and oxidation of carbon into carbon monoxide yields $9210.96\frac{KJ}{Kg}C$; while oxidation into CO_2 yields $32780.310\frac{KJ}{Kg}C$, thus the percentage loss in efficiency due to incomplete combustion can be calculated as:-

$$percent(loss) = \left[\frac{32780.310 - 9210.96}{32780.310} \times \frac{ppmCO}{ppmCO + ppmCO_2}\right] \times 100 \Bigg\} \qquad \textbf{[Eq 3.67]}$$

That is $percent(loss) = \left[\frac{yield(CO_2) - yield(CO)}{yield(CO_2)} \times \frac{ppm(CO)}{ppm(CO_2) + ppm(CO)}\right] \times 100$,

where the concentration of CO_2 and CO comes from the flue gas analysis.

3.10.9. Limitations of Coal

- Less heat value compared to oil (approximately 40%);
- Large Space required for storage(50% greater than oil);
- Difficult to metered and control flow;
- Relative ignition difficulties;
- Formation of ash and slag;

3.11. Advantages of Fluidized Bed Combustion

It is useful to consider the major advantages of a fluidized bed in the context of the historical record:-

1. Good heat transfer rates are obtained, direct contact heat transfer between gas and solid occurs at high rates because surface area per unit mass of solids is high. Heat transfer at the wall is also good primarily because of continuous and rapid particle movements to from the heat transfer surface. Good solids mixing is achieved with high heat transfer, effectively eliminates axial and radial temperature gradients, creating thereby essentially isothermal conditions.
2. SO_2 can be removed in the combustion process by adding limestone to the fluidized bed, eliminating the need for an external desulphurization process.
3. Fluidized bed combustors are inherently fuel flexible and with proper design provisions, can burn a variety of fuels with less operating difficulties.

4. Combustion at lower temperature has several benefits:-
    - Combustion temperatures are below ash fusion temperatures design of fluidized bed combustor is not as dependent on ash properties as is a conventional burners with proper design considerations,
    - Because of the reduced combustion temperatures, NOx emissions are inherently low; and capable of meeting nitrogen emission standards without the need for extensive add-on controls.
5. A fluidized bed combustor is therefore much more compact than a conventional one of the same capacity, in addition, reductions in sulfur dioxide (and trioxide) in the flue gas means that lower stack gas temperatures can be tolerated because less acid is formed as result of the combustion of water vapour. Lower stack gas temperatures result in an increase in over all plant efficiency.
6. Another advantage is the absence of pulverization equipment, resulting in further economies; also, a fluidized bed combustor can be designed to incorporate the boiler within bed, resulting in volumetric heat transfer rates that are 10 to 15 times higher and surface heat transfer rates that are 2 to 3 times higher than conventional burners.
7. Low operating costs, the absence of moving parts in a fluid bed reduces maintenance costs and down time.

3.12. Problems With Fluidized Bed Combustion

1. Feeding the coal and limestone into the bed;
2. effect of bubbling fluidization(not common in combustion);
3. control of carbon carryover with the flue gases, the generation or disposal of calcium sulphate , the quenching of combustion by the cooler water tubes within the bed and variable load operation

4. Conclusion and Recommendations

4.1. Conclusion

Nowadays resource of most types, particularly the energy resource is becoming scarce and prices are increasing from time to time. Meanwhile, due to fast population growth, improved living standards and economic developments, the energy demand of the country is increasing continuously.

Looking at the current situation in Ethiopia, it can be seen that what happens to the other commodity's price is related directly with the fluctuation (instability) in the energy prices (petroleum products). This effect is manifested, because most of the major economic sectors of the country are highly dependent on the imported fuel source, and lack of good energy source mix in the country. Consequently, it is difficult to achieve the economic development strategy and secure sustainable development within the country, as reliable supply of energy at reasonable (affordable) costs is required.

The discovered coal reserve and other promising occurrences in different part of the country, if properly managed and rationally allocated, is the potential resource of the country to reduce the development challenges of the country by replacing the imported petroleum.

The Ethiopian (Yayu) lignite coal has satisfactory heating value (energy) to meet the current energy demand of the Case Factory , moreover, burning of coal within the fluidized bed, will perform with better conversion efficiency and an acceptable level of emissions. Use of this system has more environmental merits; emissions of sulfur can be minimized to acceptable level concurrently with the combustion of coal in the fluidized bed by adding sorbent (calcium carbonate) and the low operating temperature of the fluidized bed does not allow reaction of nitrogen and oxygen to form nitrogen oxides, as a result there will be minimum NO_X products. Due to the high fusion temperature of the Yayu coal ash, there is no problem of ash fusion. In addition to these merits fluidized bed combustion system is more flexible to burn almost all fuel types and due to absence of movable parts in the system maintenance costs relatively low. But as a drawback of the system there is a production of significant amount of carbon dioxide that is the most known greenhouse gas.

It can be concluded that coal has greater potential to substitute the imported Heavy Fuel Oils in the Case Factory to meet its ever increasing energy demand. In this respect it will play an important role in reducing the hard currency, secure better reliable supply and improve energy source mix both at national and sectoral level.

Coal in the other metal industries has technical difficulties for the direct heating and reheating of the metal billet and ingot, as it will change the properties of the metal components and operating temperature is elevated (1100-1200^{O}C). Due to this fact use of coal for this purpose needs to modify the heat exchangers of the current systems. The Ethiopian coal (Yayu coal) cannot be used for the industries which need high heating value fuels, since it is a lignite coal with low heating value. From the heat loss analysis, it is shown that the loss is significantly large; recovering this energy is important to improve the thermal efficiency of the system.

4.2. Recommendations

From the findings of the literature review, discussion and analysis the following valuable points are recommended: regarding application of coal, the modified system to be used in the Case Factory and areas which need further studies.

- Availability of natural resource does not bring sustainable development, but the way how we mange and use makes a difference. Policy action regarding use of coal as an alternative source of energy in metal industries is essential.
- It is known that coal is generally scarce non-renewable resource rational and effective use of the resource is important, to do so priorities and access to use should be clearly defined for the particular resource.
- Coal should replace furnace oil in the Case Factory, since it has economic and environmental advantages and only requires miner technical adjustment in the current system.

- Sulfur removal is optimal at elevated temperatures; which creates favorable condition for the formation nitrogen oxides (NOx), therefore the operating temperature should not exceed 900°C.

Potential areas for further studies

- Significant amount of carbon dioxide will be produced in the combustion of coal, thus burning of coal; with out any t reatment of CO_2 has negative environmental impacts. If properly treated can be a marketable product to sell for factories, to be used as a raw material for different productions.
- In this thesis work analysis is done with out considering any heat recovery from the flue gas, ash and slag, better thermal efficiencies can be improved by recovering the heat from these losses.
- To improve the heating and over all efficiency of the system air supply should be preheated.
- The ash and slag produced in the combustion of coal can be used as an input in the construction industry. This in turn reduces disposal and handling cost and environmental load.

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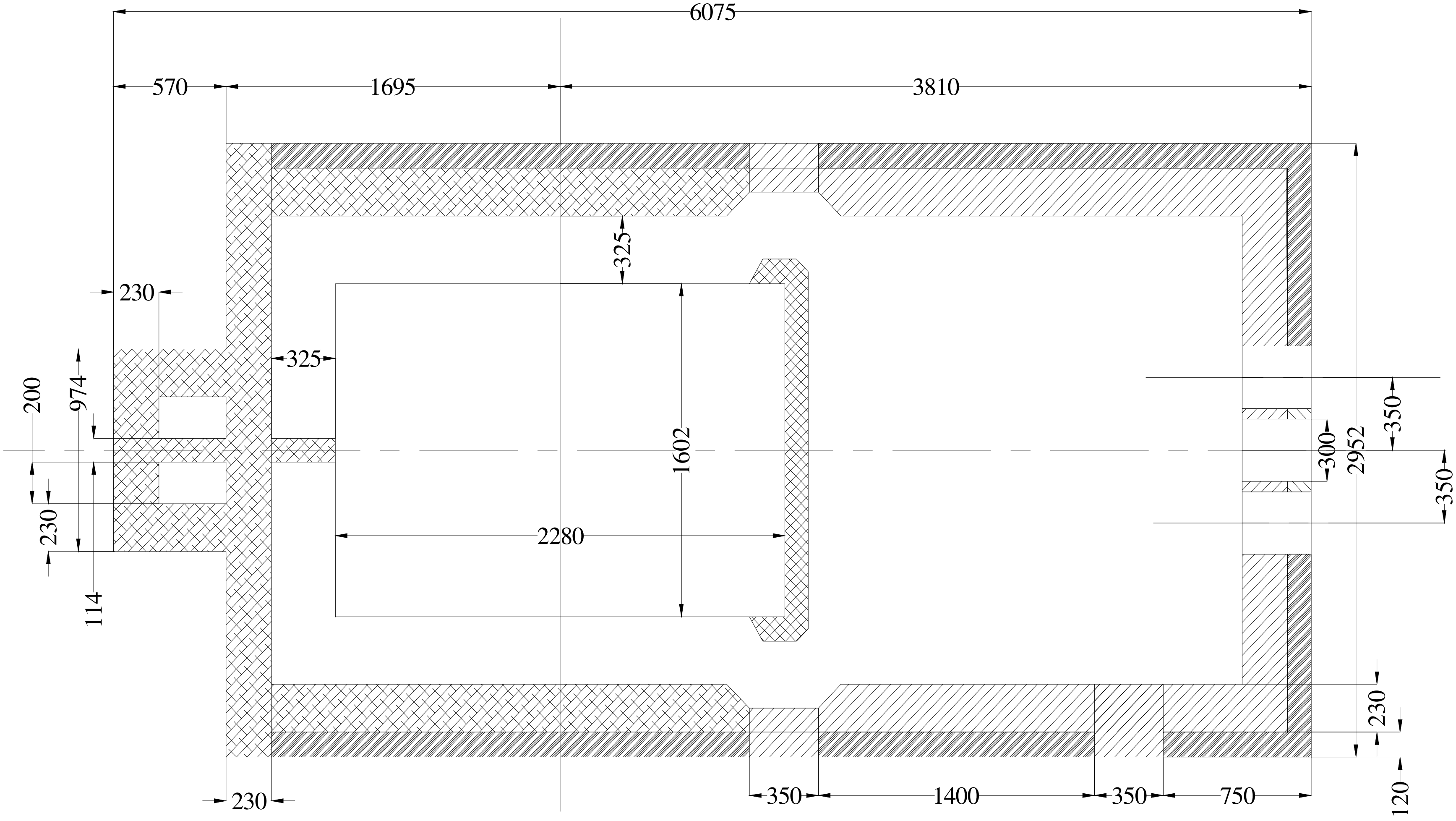
Annex (A): Furnace Drawing[25]

Figure 13: Existing Furnace Top View



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[25] All dimensions are in mm

Figure 14: Existing Furnace Front View

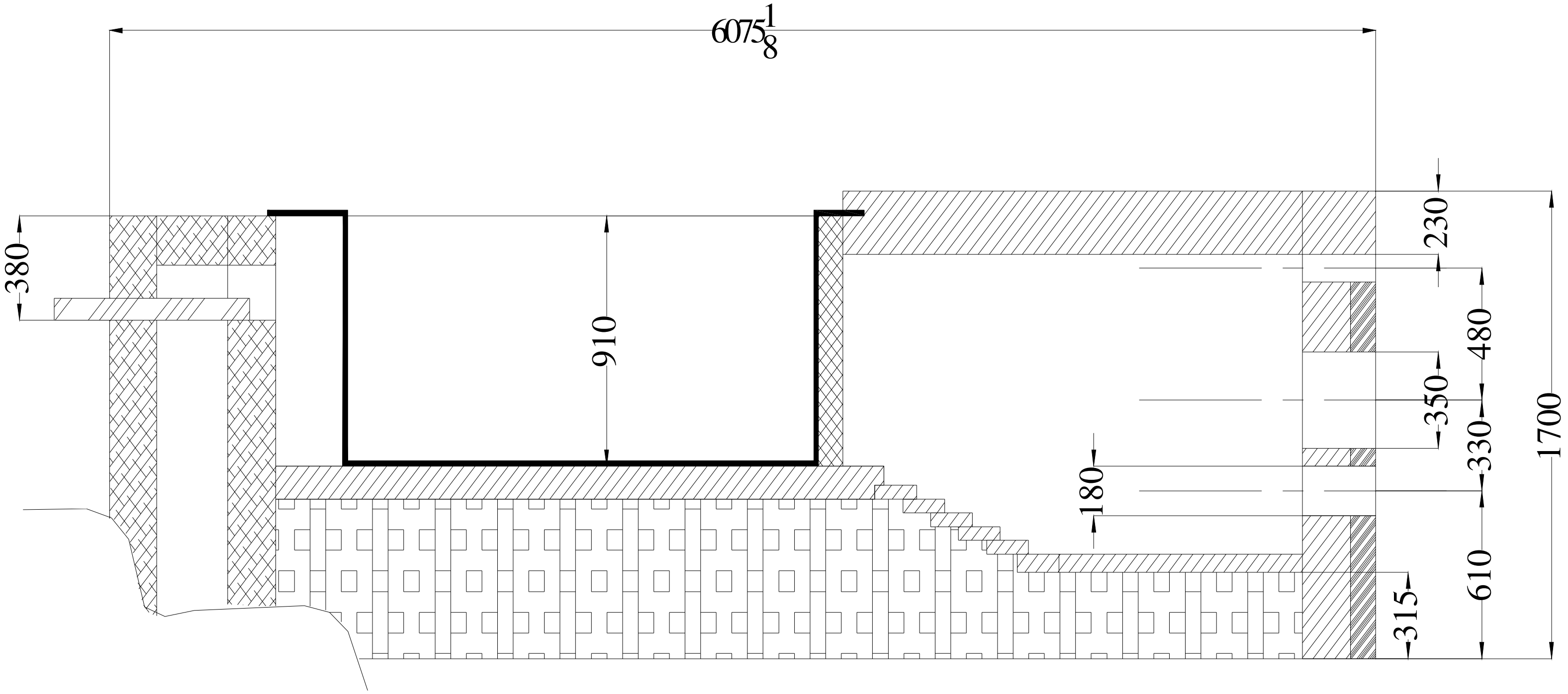


Figure 15: Modified Furnace Top View

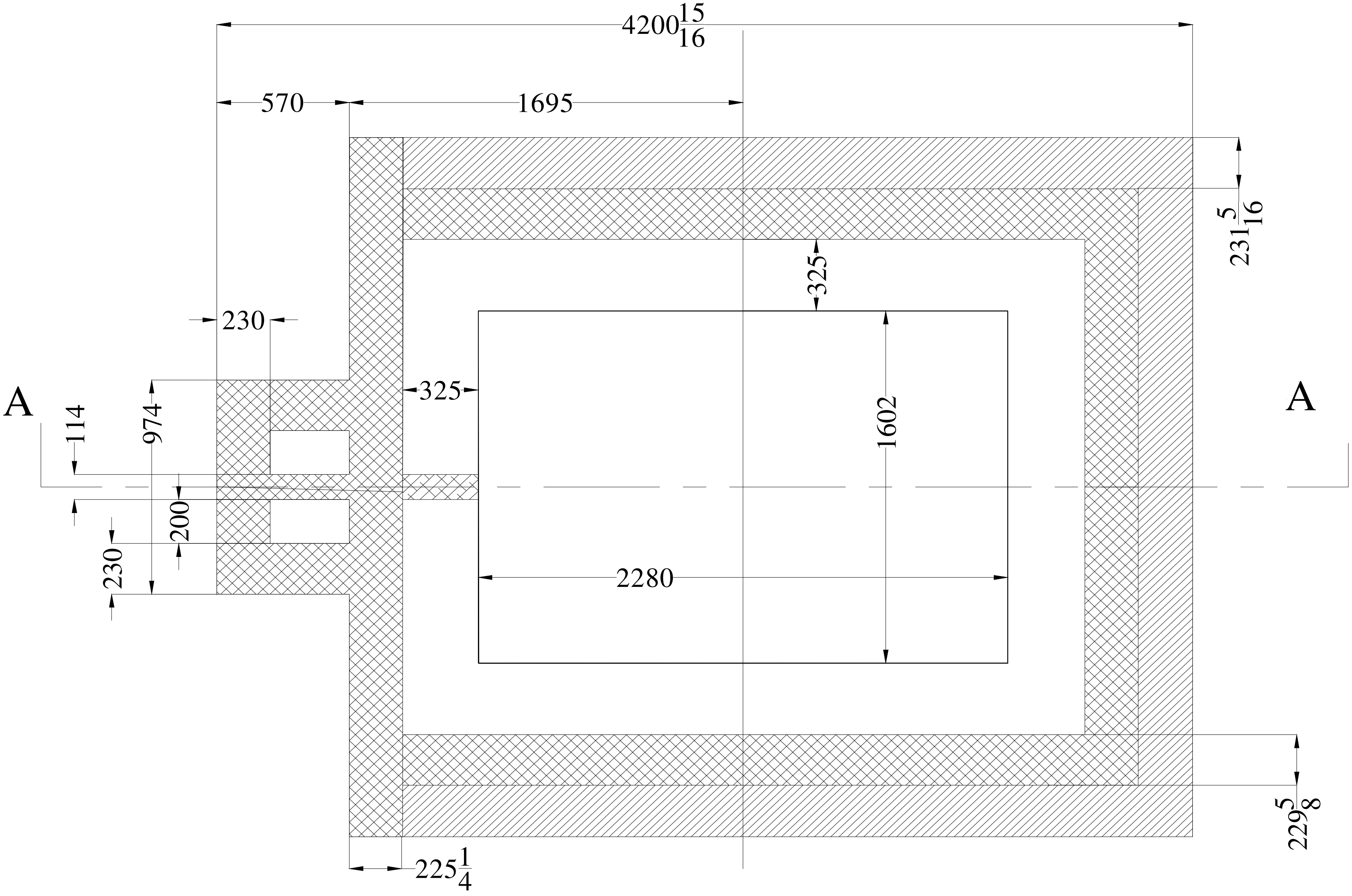
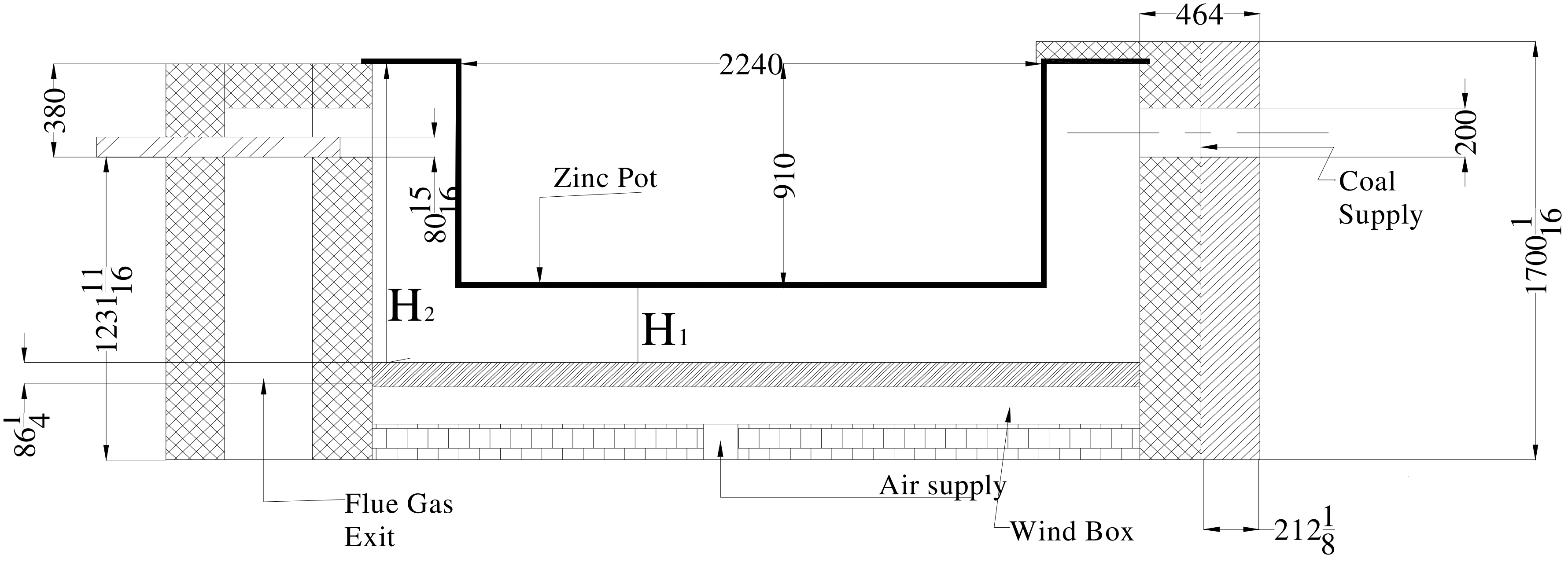


Figure 16: Modified Furnace Front View: Section A-A



Signed Declaration

I declare that the thesis for the M.Sc. degree at the University of Addis Ababa, hereby submitted by me, is my original work and has not previously been submitted for a degree at this or any other university, and that all reference materials contained therein have been duly acknowledged.

Name: Elfu Amare Demoze

Signature: --------------